VOLUME IV OF VIII
MOTTOLO SITE
REMEDIAL INVESTIGATION REPORT
APPENDICES B-1 THROUGH B-2

Submitted to:

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September 28, 1990
Balsam Project 6185/818

(S4324COV)

APPENDIX B-1

WESTON GEOPHYSICAL CORPORATION REPORT
DECEMBER 1988

GEOPHYSICAL INVESTIGATIONS

MOTTOLO SITE

RAYMOND, NEW HAMPSHIRE

Prepared for

BALSAM ENVIRONMENTAL CONSULTANTS, INC.

APRIL 1989

Weston Geophysical

CORPORATION

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1.0 INTRODUCTION AND PURPOSE

A geophysical investigation was performed for Balsam Environmental Consultants, Inc. at the Mottolo Superfund site in Raymond, New Hampshire during the period of October 31 through November 10, 1988. The geophysical survey methods used in this investigation were seismic refraction profiling, electromagnetic terrain conductivity (EM) and magnetics. The objectives of this investigation were to acquire information to assist in contaminant plume identification and in refining the proposed location of soil borings and monitoring wells.

2.0 LOCATION AND SURVEY CONTROL

The general area of investigation is shown on Figure 1, a segment of the Mt. Pawtuckaway and Sandown, New Hampshire United States Geologic Topographic Quadrangle maps. The specific lines of coverage are shown on Figures 2 and 3. The topographic base map used for Figures 2 and 3 was provided to Weston Geophysical by Balsam Environmental Consultants. Line locations were plotted on this map based on field observations, measured distances and compass bearings from cultural and topographical features. Line locations have an estimated accuracy of approximately ± 10 feet. Vertical control for the seismic refraction profiles (Figures 4 and 5) was determined from the topographic map (Figure 2) and field observations noted by the geophysical survey crew. Ground surface is believed to have an accuracy of approximately ± 2 feet.

3.0 METHODS OF INVESTIGATION

3.1 Seismic Refraction

Seismic refraction data were acquired using the Weston developed WesComp™ field computer digital data acquisition and processing system. Approximately 6,390 linear feet of seismic data were acquired using 24-trace, 400 foot spread lengths with 10- and 20- foot geophone spacings, or 250 foot spread lengths with 10 foot geophone spacings. Seismic energy was generated with small explosive charges buried two to four feet or with a Betsy seisgun in areas of close proximity to private homes. An expanded discussion of the seismic refraction survey method and a listing of travel time arrivals is included in Appendix A.

The objective of the seismic refraction survey was to acquire information on the subsurface stratigraphy and assist in identifying possible weathered or fractured bedrock zones.

3.2 Electromagnetic Terrain Conductivity (EM)

The EM measurements were conducted with Geonics EM-31 and EM-34-3 terrain conductivity meters. The EM-31 data were collected with a continuous strip chart recorder. This is a walk-over technique that measures the average earth conductivity in a localized area to an approximate depth of 15 to 20 feet. Approximately 5,590 linear feet of EM-31 data were acquired (see Figure 3 for line locations).

The EM-34-3 data were acquired at 25 foot intervals in both the horizontal and vertical dipole modes with a 10 meter coil spacing. The effective depth of penetration is approximately 25 and 50 feet for the horizontal and vertical dipole modes, respectively. An expanded discussion of the electromagnetic terrain conductivity method of investigation and tabulated EM-31 and EM-34 readings are included as Appendix B.

The EM data were acquired to assist in the identification of conductive, contaminant plume migration in the overburden and bedrock. Contaminant plumes are often associated with areas of higher than background conductivity.

3.3 Magnetics

The magnetic measurements were acquired using a Geometrics portable proton precession magnetometer. Several measurements were acquired at each station and compared for repeatability. In general, all values were repeatable to one gamma with the exception of a small area on Line A between stations 6+10 and 6+50. At this location the magnetic values fluctuated as much as ±100 gammas. Additional readings were acquired at these stations so that an average value could be determined. Base stations measurements were acquired on Line D, Station 3+00 approximately every hour to determine the amount of diurnal variation. The diurnal variation appears to be approximately 13 gammas over a two hour period. This variation is generally minor in comparison to the magnitude of a magnetic anomaly associated with a bedrock fault or fracture. Therefore, the readings were not corrected for diurnal variation.

A total of approximately 1,600 feet of magnetic data were acquired along lines A,B,C,D and H. Anomalous magnetic readings in the vicinity of low seismic-velocity bedrock would help to confirm the presence of a geologic feature associated with fractured or highly weathered bedrock. A more detailed discussion of the magnetic survey method and tabulated magnetic readings are included in Appendix C.

4.0 DISCUSSION OF RESULTS

4.1 Seismic Refraction

The results of the seismic refraction investigation are presented in profile form in Figures 4 and 5. These profiles show the overburden thickness, depths to the water table (top of 5,000 ft/sec layer) and bedrock, and the seismic velocity values of the various layers that were detected.

Using seismic data alone, materials can be placed into broad classifications based on the velocity of the seismic waves transmitted through them. While each velocity value does not have a unique material correlation, most bedrock as well as overburden types fall within the restricted velocity ranges given below.

Overburden

The velocity range of 1,000 to 2,000 ft/sec is indicative of loose, unconsolidated, and unsaturated overburden materials (often fluvial deposits).

Seismic velocity values of 4,800 to 5,300 ft/sec are commonly indicative of water-saturated, fluvial deposits.

Bedrock

Highly weathered or fractured bedrock will have seismic velocity values spanning virtually the entire range of overburden values. However at the low end of this range, the bedrock will exhibit the mechanical characteristics of overburden.

Seismic velocities in the range of 10,000 to 13,000 ft/sec are indicative of moderately weathered bedrock, while seismic velocities in the range of 13,000 to 16,000 ft/sec are indicative of slightly weathered bedrock. Seismic velocities in excess of 16,000 ft/sec are indicative of massive, sound, unweathered bedrock with little to no fracturing.

An analysis of the results (Figures 4 and 5) of the seismic refraction investigation indicates that bedrock is shallow (2 to 30 feet deep) at the southern end of the area investigated (Lines A, B and C) and deepens (15 to 45 feet deep) to the north (Lines I and H). Bedrock velocities generally are in the range of 13,000 to 16,000 ft/sec indicating slightly weathered/fractured bedrock conditions. However, areas of low velocity (10,000 ft/sec or less) bedrock indicative of highly weathered fractured permeable bedrock were detected in the vicinity of Line A Stations 5+80 to 5+90, Line B Stations 3+30 to 3+80, Line D Stations 5+90 to 6+10 and Line F Stations 0+00 to 1+50. The low velocity zone detected on Lines A, B, and D is associated with distinctive bedrock topography changes and possibly indicative of a significant fracture zone.

Saturated overburden materials (5,000± ft/sec) were detected on all the seismic lines. This layer is thickest to the north along Lines H and I and appears to also be thickening to the west of Line I.

4.2 Electromagnetic Terrain Conductivity (EM)

The results of the EM investigations are presented on Figure 6 and Figure 7. Figure 6 is a conductivity contour map of the EM-31 data acquired in the vicinity and down-gradient of the Mottolo site. Figure 7 presents profiles of EM-34 conductivity data acquired along seismic lines.

Conductivity values measured by the EM-31 investigation are generally in the range of 0.7 to 3 mmhos/meter with several reverse polarity readings (RP). The reverse polarity readings are caused by nearby buried or surficial metal objects. Most of the RP readings detected at the Mottolo site appear to correlate with metalic objects observed in the field (scrap metal, well casing, buildings, etc.).

Slightly higher than average EM values (greater than 1.5 mmhos/meter) were detected in the vicinities of Line A (Stations 4+00 to 6+60), Line 4 (Stations 0+85 to 2+60), Line 8 (Stations 0+00 to 1+30 and 2+60 to 3+35), Line 10 (Stations 0+30 to 1+80), Line 11 (Stations 5+05 to 5+25) and Line D (Stations 5+40 to 6+40). These slightly higher conductivity values are typical of lateral variations we have determined for conductivity values associated with a sand and/or gravel overburden material. It should also be noted that the slightly higher conductivity values detected on Line A between Stations 5+20 and 6+60 and Line 4 between Stations 1+60 and 2+60 are 0.5 mmhos higher than Stations 0+00 to 4+00 on Line A and therefore of possible interest for contaminant detection.

Therefore, three possible explanations for these slightly higher conductivity values are: higher moisture contents of the soil, higher clay contents of the soil, or the presence of small quantities or small concentrations of a conductive contaminant.

The other positions with slightly higher conductivity values (Line A (Stations 4+00 to 5+20), Line 4 (Stations 0+85 to 1+60), Line 8 (Stations 0+00 to 1+30 and 2+60 to 3+35), Line 10 (Stations 0+30 to 1+80), Line 11 (Stations 5+05 to 5+25), and Line D (Stations 5+40 to 6+40) are attributed to surficial metal or shallow water saturated materials.

Conductivity values measured by the EM-34 investigation are generally in the range of 1 to 4 mmhos/meter. Higher values of 6 mmhos/meter were obtained on the ends of Lines F and H and are probably associated with nearby powerlines and utilities.

4.3 Magnetics

The results of the magnetic investigation are presented as Figure 8. Total field magnetic values detected during this investigation ranged from approximately 55,350 to 57,140 gammas. Background for the Mottolo site appears to be in the range of 55,400 to 55,550 gammas. The background range was determined by averaging values from a relatively widespread area with no anomalous values. Magnetic anomalies were detected in the vicinity of Line D Stations 4+00 to 4+40, Line B Station 4+20 to 4+55 and on Line A Stations 4+70 to 5+00 and 6+00 to 6+65. The anomalies on Lines A and D are near ferrous metal objects (wells, culverts, pipes etc.) and therefore are probably caused by these cultural features. However, the magnetic anomaly on

Line B may have a geologic source; background magnetic values are distinctly different either side of this anomaly and this anomaly is near a seismic low velocity zone. Geologic features that could be the source of this anomaly are faults, dikes or bedrock lithology changes.

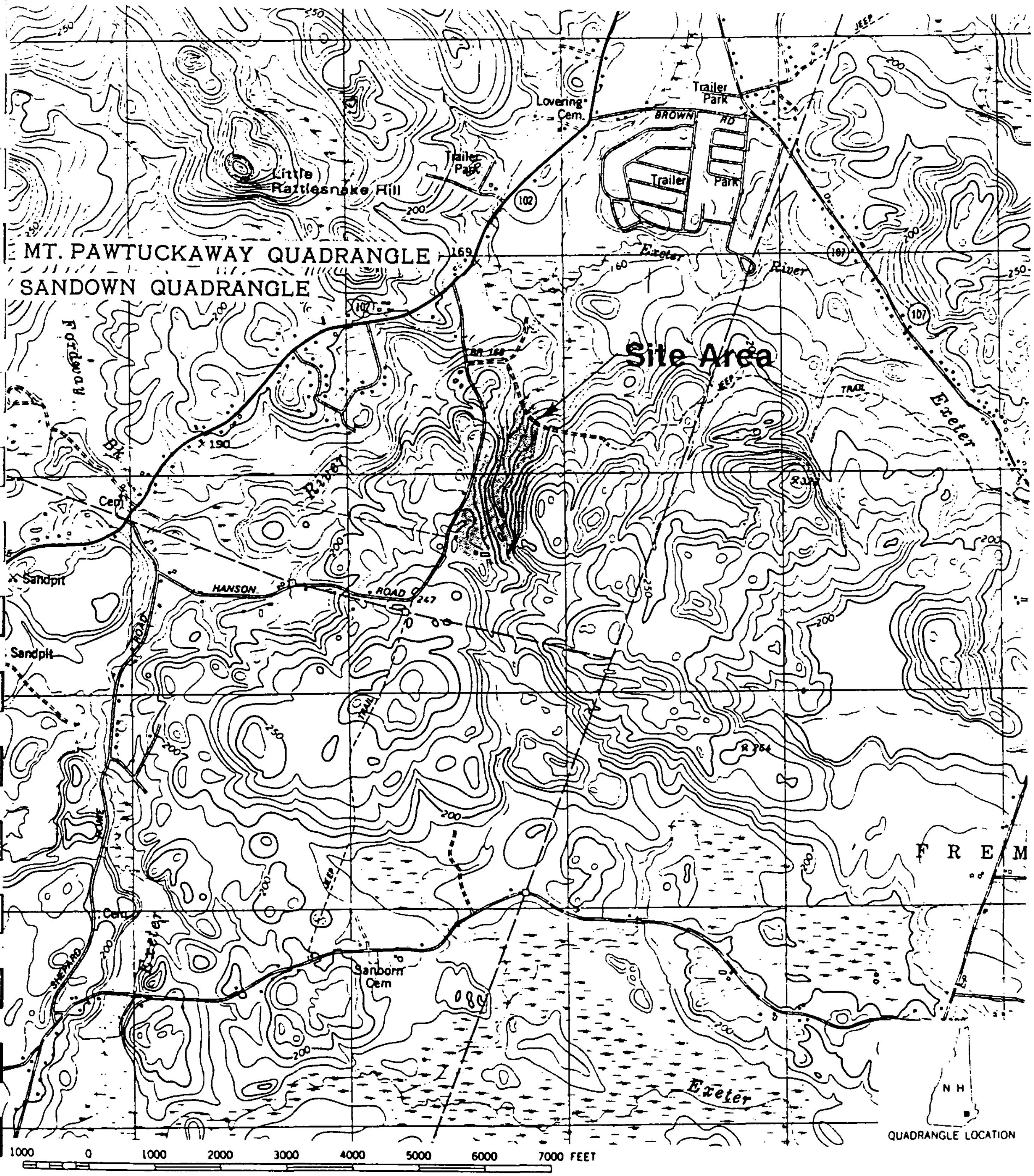
5.0 SUMMARY

The results of the geophysical investigation conducted at the Mottolo Superfund site in Raymond, New Hampshire indicate that the depth to bedrock in the area investigated ranges from approximately 2 feet to 45 feet. Generally, the bedrock is relatively high velocity (13,000 to 16,000 ft/sec) indicating a slightly fractured/weathered condition. However, several areas of low velocity (10,000 ft/sec or less) bedrock were detected in the vicinity of Line A Stations 5+80 to 5+90, Line B Stations 3+30 to 3+80, Line D Stations 5+90 to 6+10 and Line F Stations 0+0 to 1+50. The low velocity zones detected on Lines A, B, and D are associated with distinct bedrock topographic changes and are most likely indicative of zones of fractured, permeable bedrock.

EM results indicate that conductivity values generally fall in the range of 0.7 to 4 mmhos/meter, which is considered typical for a sand and gravel overburden area. However, slightly higher conductivity values (0.5 mmhos/meter greater than average) were detected in the vicinity of Line A, Stations 5+20 to 6+60 and Line 4, Stations 1+60 and 2+60. These slightly higher conductivity values could be attributed to either soil moisture content, material changes or a small quantity or concentration of conductive contamination. No other conductivity trends indicative of a contamination plume were detected.

The results of the magnetic investigation indicate numerous anomalies due to ferrous metal objects (well casing, culverts etc.). One magnetic anomaly on Line B in the vicinity of Stations 4+20 to 4+55 appears to have a geological source and is in close proximity to a low velocity bedrock area.

FIGURES



GEOPHYSICAL INVESTIGATIONS MOTTOLO SITE RAYMOND, NEW HAMPSHIRE prepared for BALSAM ENVIRONMENTAL CONSULTANTS, INC.	Area of Investigation	
	Weston Geophysical	FIG. 1

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	Geophysical Coverage		
	Seismic Refraction	EM-34	Magnetics
Line A	●	●	3+50 to 8+00
Line B	●	●	1+50 to 5+50
Line C	●	●	0+00 to 2+00 and 4+50 to 7+00
Line D	●	0+25 to 12+00	4+00 to 7+00
Line E	●	●	—
Line F	0+30 to 2+50 and 2+80 to 7+80	0+00 to 5+50	—
Line G	●	0+50 to 1+50	—
Line H	●	5+75 to 8+50	7+00 to 9+00
Line I	●	—	—

N

0 200 500
scale in feet

Note: Line locations are based on field obervations and are approximate.

GEOPHYSICAL INVESTIGATIONS MOTTOLO SITE RAYMOND, NEW HAMPSHIRE prepared for BALSAM ENVIRONMENTAL CONSULTANTS, INC.	Plan Map Seismic Refraction, EM-34, and Magnetic Coverage	
	Weston Geophysical	FIG. 2

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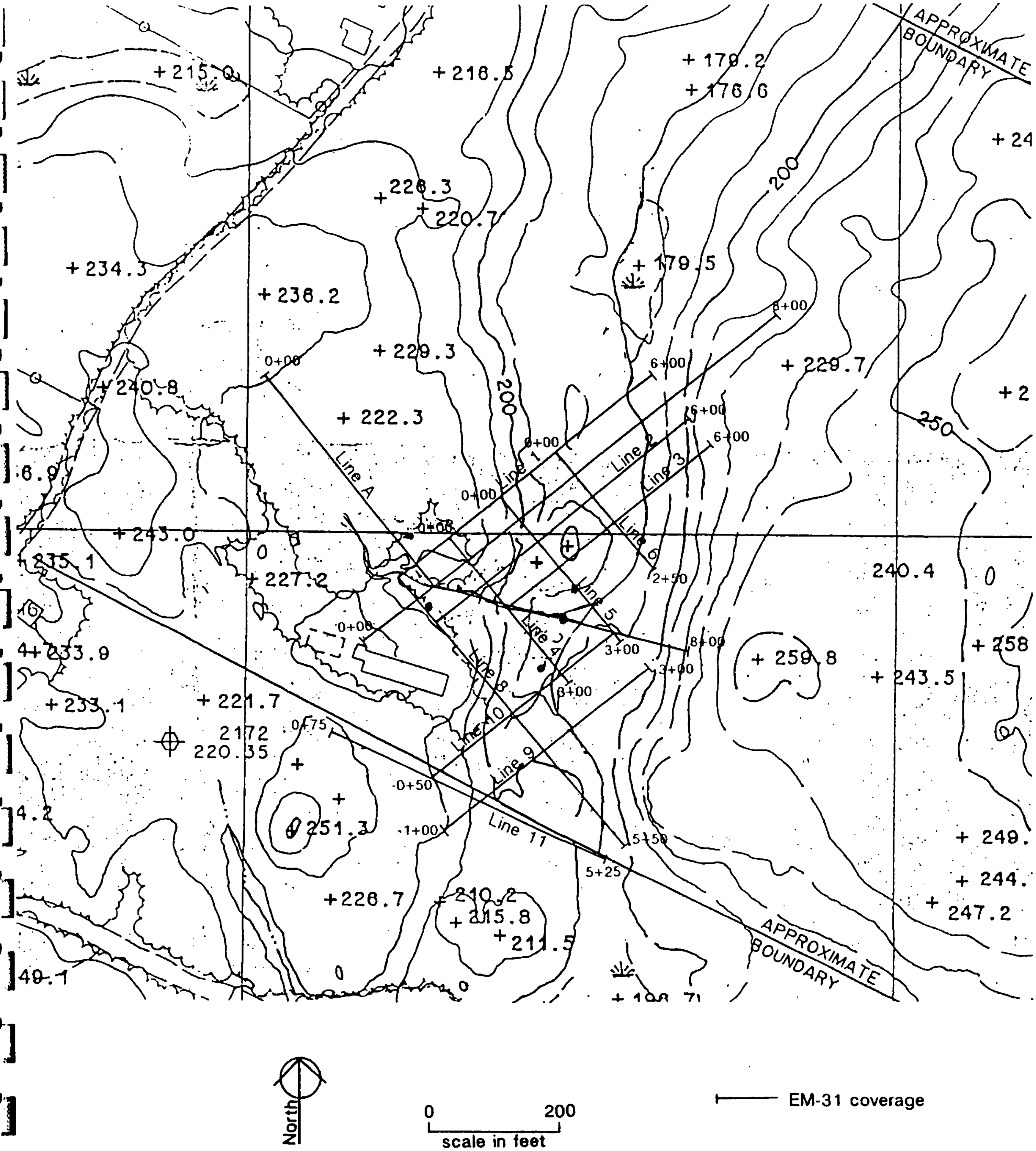

GEOPHYSICAL INVESTIGATIONS MOTTOLO SITE RAYMOND, NEW HAMPSHIRE prepared for BALSAM ENVIRONMENTAL CONSULTANTS, INC.	Plan Map EM-31 Coverage	
	Weston Geophysical	FIG. 3

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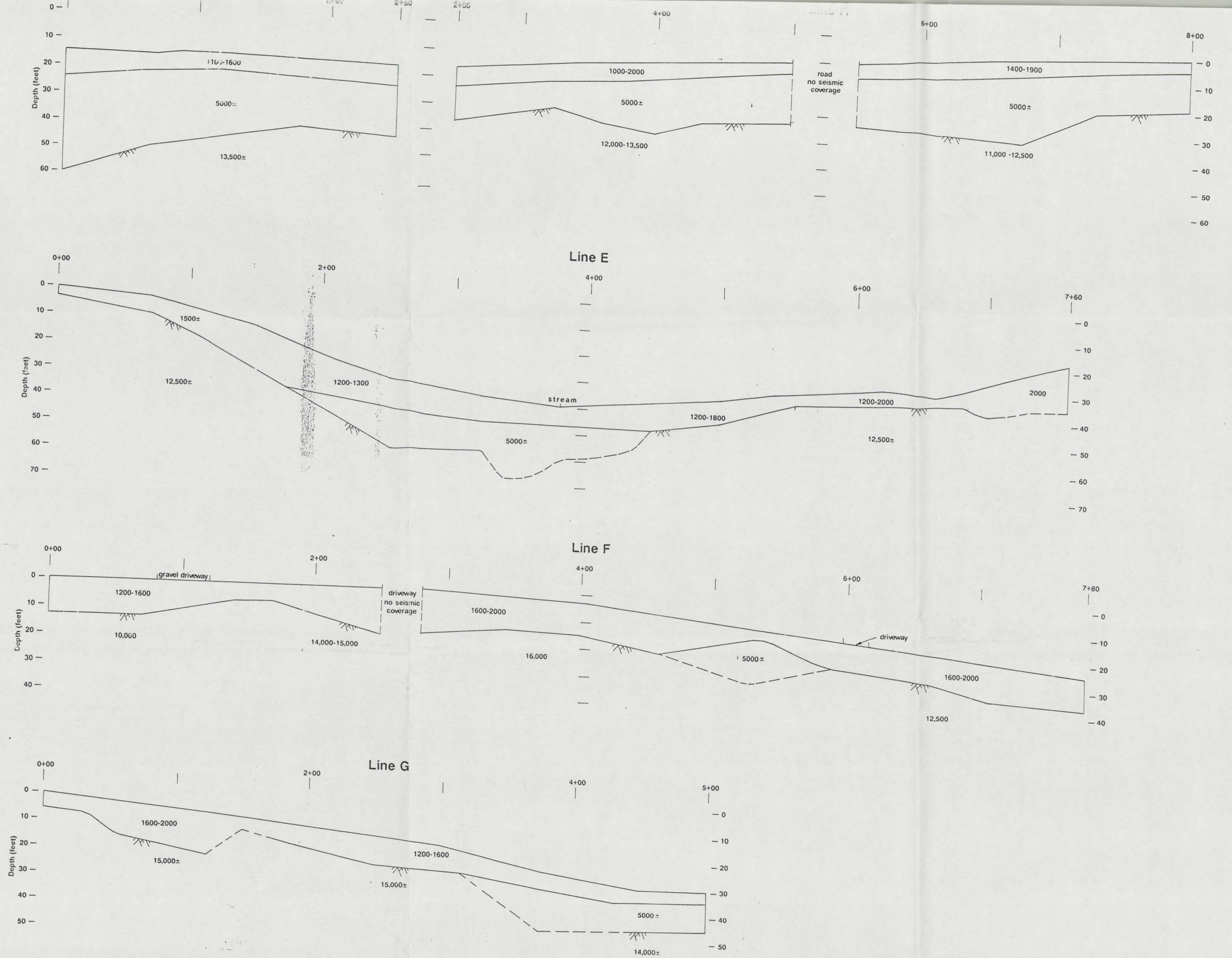
Line D
0+00
2+00
4+00
6+00
8+00
10+00
12+00
Depth (feet)
Line A
1400-1600
1400-1600
13,000
1400-1600
16,000±
Line B
13,500
stream
possible
fracture zone
1400-1600
5000±
16,000±
1400-1600
Line C
5000±
15,500±
Line C
Depth (feet)
1600-2000
13,000±
2000±
14,500
5000±
stream
Line D
1600±
5000±
15,000±
1600-2000
15,000-16,000
Line B
Depth (feet)
1400-1600
15,000±
1400-1600
5000±
5000±
possible
low velocity
bedrock zone
1400-1600
Line D
14,000±
5000±
stream
15,000-16,000
1200-1600
5000±
Line A
Depth (feet)
1200-1600
5000±
16,000±
1200-1600
5000±
Line D
1800-2100
15,000±
possible
fracture zone
5000±
stream
1700-1800
15,000±
5000±
Notes:
Seismic velocities are in feet/sec.
Dashed lines indicate velocities
with uncertain geometries
0
50
100
scale in feet
GEOPHYSICAL INVESTIGATIONS
MOTTOLO SITE
RAYMOND, NEW HAMPSHIRE
prepared for
BALSAM ENVIRONMENTAL
Seismic Refraction Profiles
Lines A thru D



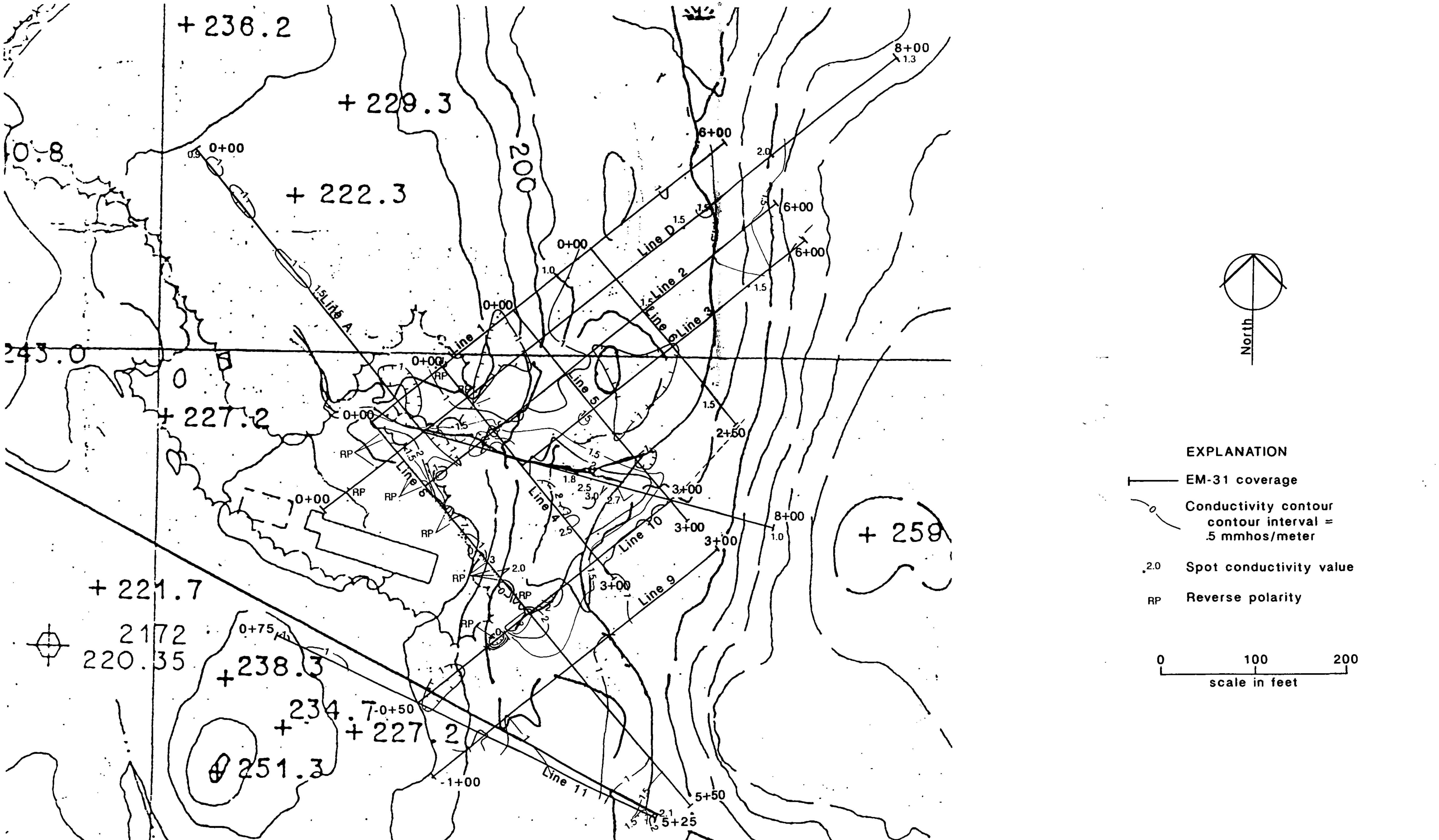
Notes:

Seismic velocities are in feet/sec.

Dashed lines indicate velocities with uncertain geometries

0 50 100
scale in feet

GEOPHYSICAL INVESTIGATIONS MOTTOLO SITE RAYMOND, NEW HAMPSHIRE prepared for BALSAM ENVIRONMENTAL CONSULTANTS, INC.	Seismic Refraction Profiles Lines E thru I
	Weston Geophysical — FIG. 5



GEOPHYSICAL INVESTIGATIONS
MOTTOLO SITE
RAYMOND, NEW HAMPSHIRE
prepared for
BALSAM ENVIRONMENTAL CONSULTANTS, INC.

EM-31 Survey Coverage Plan and Conductivity Contours

Weston Geophysical

FIG. 6

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GEOPHYSICAL INVESTIGATIONS
MOTTOLO SITE
RAYMOND, NEW HAMPSHIRE
prepared for
BALSAM ENVIRONMENTAL
CONSULTANTS, INC.

Conductivity Profiles
EM-34 Data

Weston Geophysical

FIG.

GEOPHYSICAL INVESTIGATIONS
MOTTOLO SITE
RAYMOND, NEW HAMPSHIRE
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CONSULTANTS, INC.

Magnetic Profiles

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FIG. 8

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APPENDIX A

SEISMIC REFRACTION SURVEY METHOD OF INVESTIGATION

GENERAL CONSIDERATIONS

The seismic refraction survey method is a means of determining the depths to a refracting horizon and the thickness of major seismic discontinuities overlying the high-velocity refracting horizon. The seismic velocities measured by this technique can be used to calculate the mechanical properties of subsurface materials [moduli values], as well as for material identification and stratigraphic correlation.

Interpretations are made from travel time curves showing the measurement of the time required for a compressional seismic wave to travel from the source ["shot"] point to each of a group of vibration sensitive devices [seismometers or geophones]. The geophones are located at known intervals along the ground surface, as shown in Diagram A. Various seismic sources may be used, including a drop weight, an air gun, and small explosive charges.

FIELD PROCEDURE FOR DATA ACQUISITION

Weston Geophysical Corporation uses a seismic recording technique of continuous profiling and overlapping spreads for engineering and ground water investigations. The seismic refraction equipment consists of a Weston Geophysical trace amplifier, Model USA780, with either a WesComp™ [a field computer system developed by Weston Geophysical], or a recording oscillograph.

Continuous profiling is accomplished by having the end shot-point of one spread coincident with the end or intermediate position shot-point of the succeeding spread. The spread length used in a refraction survey is determined by the required depth of penetration to the refracting horizon. It is generally possible to obtain adequate penetration when the depth to the refracting horizon is approximately one-third to one-quarter of the spread length.

In general, "shots" are located at each end and at the center of the seismic spread, Diagram B. The configuration of the geophone array and the shot point positions are dependent upon the objectives of the seismic array.

As mentioned above, seismic energy can be generated by one or more of several sources.

The seismometer or geophone is in direct contact with the earth and converts the earth motion resulting from the shot energy into electric signals; a moving coil electromagnetic geophone is generally used. This type of detector consists of a magnet permanently attached to a spiked base which can be rigidly fixed to the earth's surface. Suspended within the magnet is a coil-wrapped mass. Relative motion between the magnet and coil produces an electric current, with a voltage proportional to the particle velocity of the ground motion.

The electric current is carried by cable to the recording device which provides simultaneous monitoring of each of the individual geophones. The operator can amplify and filter the seismic signals to minimize background interference. For each shot the seismic signals detected by a series of geophones are recorded on either photographic paper or magnetic tape, depending on job requirements. Included on each shot record is a "time break" representing the instant at which the shot was detonated.

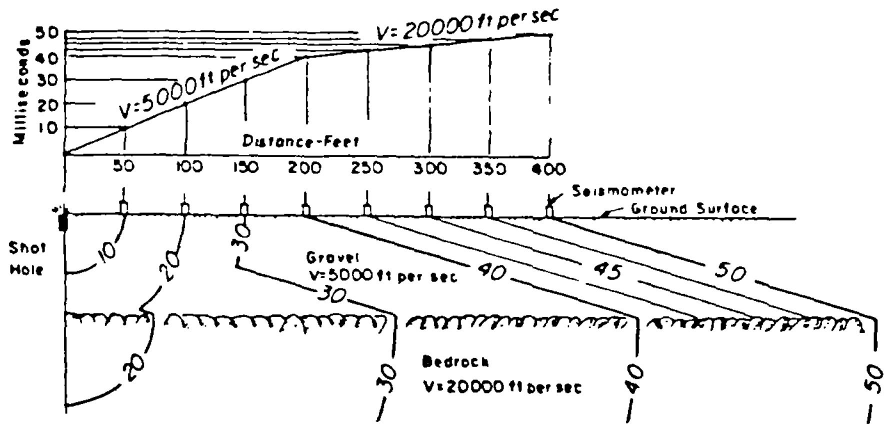
INTERPRETATION THEORY

The elastic wave measured in the seismic refraction method, the "P" or compressional wave, is the first arrival of energy from the source at the detector. This elastic wave travels from the energy source in a path causing adjacent solid particles to oscillate in the direction of wave propagation. Diagram A shows a hypothetical subsurface consisting of a lower velocity material above a higher velocity material. At smaller distances between source and detector the first arriving waves will be direct waves that travel near the ground surface through the lower velocity material. At greater distance, the first arrival at the detector will be a refracted wave that has taken an indirect path through the two layers. The refracted wave will arrive before the direct wave at a greater distance along the spread because the time gained in travel through the higher-speed material compensates for the longer path. Depth computations are based on the ratio of the layer velocities and the horizontal distance from the energy source to the point at which the refracted wave overtakes the direct wave.

Generally the interpretation is by one or more of several methods [W.M. Telford, et al., 1976] ray-tracing, wave front methods, delay times, critical distances. etc. In addition, either a forward or inverse interpretation can be performed using Weston's computer. Since successful refraction interpretation is based on experience, all interpretation of refraction data is performed or thoroughly reviewed by a senior staff geophysicist.

Reference

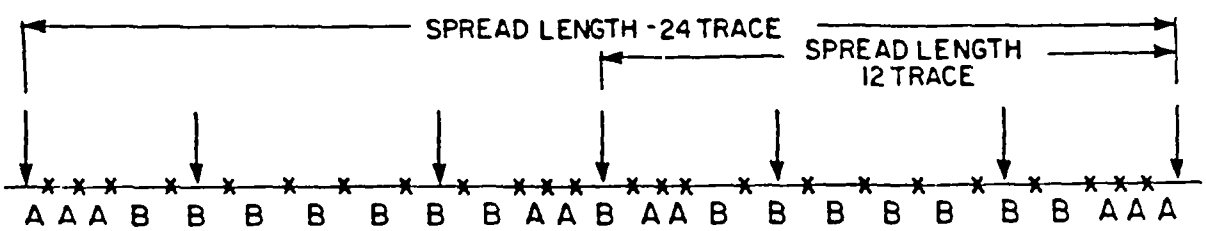
Telford, W.M.; Geldart, L.P.; Sheriff, R.E. and Keys, D.A., 1976, Applied Geophysics: Cambridge University Press.



Plot of Wave Front Advance in Two Layered Problem

Linehan, Daniel, Seismology Applied to Shallow Zone Research, Symposium on Surface and Subsurface Reconnaissance, Special Technical Publication No. 122, American Society for Testing Materials, 1951.

Diagram A



SPREAD LENGTH	GEOPHONE LOCATION A	B
400' - 24 TRACE or 200' - 12 TRACE	10	20
600' - 24 TRACE or 300' - 12 TRACE	15	30
1000 - 24 TRACE or 500' - 12 TRACE	25	50

LEGEND

↓ = GENERAL LOCATION OF "SHOT" POINT

x = GEOPHONE LOCATION

Geophone Interval-Spread Length Relationship

Diagram B

LINE # A SPREAD LENGTH 400'

SPREAD LOCATION 0+0 → 4+0 NUMBER OF TRACES 24

Seismic travel times in milliseconds

#	LOW END SHOT AT 0+0	HIGH END SHOT AT 4+0	CENTER SHOT AT 2+0	LOW QUARTER SHOT AT 1+0	HIGH QUARTER SHOT AT 3+0
1	9.5	33.0	23	19	29.8
2	11.5	34.8	24.5	—	31.2
3	12.5	31.0	20.5	16.5	27.5
4	—	29.0	19	14.5	24.5
5	16	30.0	19.5	15.5	27.0
6	17.5	29.5	18.5	8	26.0
7	18	26.8	16	8.5	23.8
8	19	25.8	15	14.5	22.3
9	21	24.3	14	16	21.3
10	22	22.8	11	17	19.3
11	24	23.6	11.5	19.5	20.3
12	24	17.6	9	19.5	19.0
13	24	19.8	6	20	16.1
14	27.5	21.3	10	22.5	16.6
15	26	17.8	9.5	21.5	14.3
16	26	16.3	11.5	21.5	11.8
17	28	16.1	15	24	12.6
18	31	16.1	17	28	9.8
19	34	16.6	20	30	12.3
20	37	15.3	22.5	33	16.3
21	32	9.6	19	28.5	13.4
22	31	6.1	17.5	27.5	11.6
23	29.5	31	16	—	10.1
24	32.5	5.6	19.5	28	12.9

LINE # A SPREAD LENGTH 400'

SPREAD LOCATION 4+0 → 8+0 NUMBER OF TRACES 24

Seismic travel times in milliseconds

#	LOW END SHOT AT 4+0	HIGH END SHOT AT 8+0	CENTER SHOT AT 6+0	LOW QUARTER SHOT AT 5+0	HIGH QUARTER SHOT AT 7+0
1	6.6	43.9	19.6	14.1	27.9
2	10.6	41.4	21.6	10.6	29.9
3	8.8	38.6	18.4	15.8	26.4
4	12.4	39.1	19.6	11.6	28.1
5	13.3	35.8	18.6	14.1	26.6
6	15.3	37.6	16.8	7.6	25.6
7	16.3	35.6	15.8	8.1	24.8
8	16.8	31.3	14.1	14.3	22.8
9	17.3	29.8	12.6	14.3	21.3
10	18.1	29.1	10.1	14.8	19.6
11	19.3	28.3	8.8	16.3	18.8
12	16.1	25.1	3.6	13.1	13.8
13	16.6	23.0	3.6	14.0	11.8
14	17.8	22.3	4.3	14.8	10.8
15	20.3	19.5	6.5	17.0	10.8
16	21.5	21.3	8.8	19.3	9.8
17	22.0	19.5	6.8	19.5	9.5
18	26.0	21.3	14.0	23.0	8.5
19	26.5	20.5	17.0	25.5	9.8
20	30.5	15.5	13.8	24.8	9.3
21	33.8	16.8	11.8	25.3	11.5
22	36.5	14.8	20.3	30.3	13.5
23	38.5	12.8	22.0	33.5	16.0
24	39	7.8	22.2	33.8	17.2

LINE # B SPREAD LENGTH 400'

SPREAD LOCATION 0+0 → 4+0 NUMBER OF TRACES 24

Seismic traveltimes in milliseconds

#	LOW END SHOT AT 0+0	HIGH END SHOT AT 4+0	CENTER SHOT AT 2+0	LOW QUARTER SHOT AT 1+0	HIGH QUARTER SHOT AT 3+0
1	10	31	21	13.5	27.5
2	9	29	18	11.5	24.5
3	11	29	18	11	25
4	8.5	29	19	9.5	25
5	15	30.5	19	11	24
6	14.5	26.5	14.5	4	20.5
7	18.5	28	16	8	22
8	20	27	14	11	20.5
9	20.5	26.5	—	12.5	20
10	23	24.5	12	13.5	18
11	23	24	11	14	18
12	25.5	24	9.5	16.5	18.5
13	22	19	5.5	13	13
14	27	21.5	11	16	14.5
15	27.5	22	12	18	15
16	29	19.5	11	19	10.5
17	28.5	17	13	19	10.5
18	29.5	16	14	20.5	8
19	34	12	17.5	24	8.5
20	34	16.5	20.5	26	15
21	36	14	20	26.5	13.5
22	36	13	21	26.5	15
23	35	10	20.5	26	15.5
24	34	7.5	20	25	14

LINE # B SPREAD LENGTH 400'

SPREAD LOCATION 4+0 → 8+0 NUMBER OF TRACES 24

Seismic traveltimes in milliseconds

#	LOW END SHOT AT 4+0	HIGH END SHOT AT 8+0	CENTER SHOT AT 6+0	LOW QUARTER SHOT AT 5+0	HIGH QUARTER SHOT AT 7+0
1	7.5	37	19.5	15	26.5
2	11	—	—	15	—
3	12	37	19	13.5	25.5
4	14	36	17.5	12	24.5
5	16	33.5	16	9.5	23
6	15	32	13.5	6	20
7	17	29	11	4.5	17.5
8	17.5	28.5	10.5	—	18
9	18	27	9	9	16.5
10	17.5	24	6.5	9	13.5
11	18	—	5.5	10	—
12	19.5	23.5	5	11.5	13
13	20.5	22	5	12.5	10
14	21.5	20.5	5.5	13	9.5
15	22	20	7	13.5	9.5
16	23	20	8	15	9
17	23	16.5	8.5	15	7
18	27	18	12	19	6.5
19	—	—	—	—	9
20	32.5	17	17.5	25	—
21	35	16	20	27	14
22	33.5	12.5	18.5	27	13
23	35.5	12	21	28	15
24	37.5	10	23	30.5	16

LINE # C SPREAD LENGTH 400'

SPREAD LOCATION 0+0 → 4+0 NUMBER OF TRACES 24

Seismic travel - times in milliseconds

#	LOW END SHOT AT 0+0	HIGH END SHOT AT 4+0	CENTER SHOT AT 2+05	LOW QUARTER SHOT AT 1+0	HIGH QUARTER SHOT AT 3+0
1	8.5	—	25.5	18	32
2	10.2	—	25	16.5	31
3	11.3	37	24	15.5	30.5
4	13.3	33.5	21	12	28
5	14.5	31	18	9	25
6	22.0	33	20	9	27
7	18.8	29.5	16.5	8.5	24
8	21.5	31	17	12	24.5
9	22.5	28	13.5	13.5	21.5
10	24.8	29.5	14.5	—	—
11	26.8	28.5	12.5	17.5	22
12	25.8	25	8	17	18.5
13	28.3	26	8	20	19.5
14	29.6	24.5	10	21	—
15	30.3	24	12	22	17
16	29.1	21	12	—	12
17	32.6	21	15	24	10.5
18	33.1	19	17	25.5	7
19	37.1	19	21	29	9
20	35.8	13.5	19.5	27.5	8.5
21	33.8	9	19	27	9.5
22	35.1	7	20	—	12.5
23	38.1	6.5	21.5	30.5	14.5
24	—	6	23.5	32.5	17.5

LINE # C SPREAD LENGTH 400'

SPREAD LOCATION ____ NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 4+05	HIGH END SHOT AT 8+0	CENTER SHOT AT 6+0	LOW QUARTER SHOT AT 5+0	HIGH QUARTER SHOT AT 7+0
1	3	35	26	22.5	30
2	4	34	24	20.5	—
3	8.2	34	24	20	28
4	—	33	23.5	18.5	27.5
5	17	—	22.5	17	26.5
6	17	29	19	9	23
7	—	28.5	18	9	22
8	21	28	17.5	14.5	21.5
9	—	27	16	17	20.5
10	—	26.5	13.5	19.5	19.5
11	—	24.5	10	18.5	18
12	—	26	9.5	21.5	20
13	—	24	8	22	17
14	27	22.5	9.5	23	15.5
15	27	22	13.5	22.5	14
16	27	19	16	24	11.5
17	28	18.5	16.5	24.5	10.5
18	28.5	17	17	—	7
19	29.5	16.5	18	26.5	6
20	30.5	13.5	18.5	27.5	7
21	33	13	21	30	10.5
22	36	11.5	25	33	15.5
23	37.5	11	26.5	—	17
24	36	7.5	26	33	17

LINE # D SPREAD LENGTH 400'

SPREAD LOCATION 0+0 → 4+0 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 0+0	HIGH END SHOT AT 4+0	CENTER SHOT AT 2+0	LOW QUARTER SHOT AT 1+0	HIGH QUARTER SHOT AT 3+0
1	9.9	29.6	16.6	—	13.1
2	13.9	28.4	17.1	13.9	22.9
3	15.4	30.4	18.1	15.4	22.1
4	18.8	31.8	20.1	17.4	24.8
5	19.3	29.8	17.6	14.8	—
6	18.3	28.1	15.3	9.1	20.3
7	18.8	24.8	13.1	9.3	18.8
8	20.8	24.6	11.6	14.1	16.6
9	21.1	21.6	8.3	12.8	13.6
10	—	19.6	5.3	13.1	11.8
11	23.3	19.1	6.3	14.6	11.6
12	—	20.6	7.6	16.1	11.8
13	—	18.8	7.3	18.0	8.8
14	27.3	18.3	6.8	—	7.6
15	28.8	17.0	—	18.3	8.3
16	34.5	16.3	8.8	19.8	8.5
17	36.5	14.5	8.8	19.8	5.8
18	—	12.8	9.3	19.8	4.8
19	—	13.0	12.0	21.8	6.3
20	32.5	12.8	13.5	23.8	8.5
21	35.0	12.3	14.8	24.8	9.3
22	—	10.0	14.0	24.8	8.0
23	—	11.0	—	23.8	12.0
24	—	8.8	16.8	27	10.5

LINE # D SPREAD LENGTH 400'

SPREAD LOCATION 4+0 → 8+0 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 4+0	HIGH END SHOT AT 8+0	CENTER SHOT AT 6+0	LOW QUARTER SHOT AT 5+0	HIGH QUARTER SHOT AT 7+0
1	8.6	—	19.1	12.1	33.1
2	9.9	40.1	18.4	11.6	31.4
3	11.1	39.8	17.4	9.8	29.6
4	10.6	38.1	15.1	7.8	28.6
5	12.6	—	14.3	8.3	29.1
6	11.6	—	12.3	5.8	26.3
7	9.1	—	11.3	4.8	24.3
8	11.1	35.6	10.6	6.6	22.8
9	13.1	27.8	8.1	5.8	20.6
10	15.8	—	6.6	6.6	18.1
11	16.3	28.3	5.6	8.6	19.3
12	15.8	25.8	3.8	8.6	17.8
13	17.8	23.3	3.8	10.3	16.8
14	22.8	27.3	8.6	15.0	20.8
15	23.5	28.0	10.5	15.8	20.0
16	25.3	24.5	14.0	18.5	18.5
17	25.8	23.0	15.5	19.5	16.3
18	28.5	24.3	17.0	21.5	9.3
19	32.0	25.5	20.3	24.5	10.5
20	18.5	23.0	21.8	26.3	17.8
21	36.0	19.3	23.5	28.0	21.8
22	36.3	15.8	20.0	28.8	23.3
23	38.0	14.0	25.2	30.8	23.8
24	—	10	27.5	—	25.5

LINE # D SPREAD LENGTH 400'

SPREAD LOCATION 8+0 → 12+0 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 8+0	HIGH END SHOT AT 12+0	CENTER SHOT AT 10+0	LOW QUARTER SHOT AT 9+0	HIGH QUARTER SHOT AT 11+0
1	8.5	44	—	21.5	—
2	12.5	44	31.5	21	36.5
3	13.5	42.5	30.5	20	34
4	15.5	41	28.5	—	33
5	20	41	27.5	18.5	—
6	20	39	25.5	10	31
7	21.5	38	24	11	29
8	22.5	36	21	16.5	28
9	23	35	20.5	17.5	27
10	25	33	16	19	25
11	26	32.5	13.5	20.5	24
12	25	33	9	20	25
13	28.5	32	10	23.5	24
14	30	—	12	25	—
15	30.5	30.5	15.5	25.5	23
16	31	29	22	26.5	20
17	33	28.5	23.5	28	15.5
18	34.5	28.5	26	30	9.5
19	34	24	25	28.5	8.5
20	37.5	22.5	23.5	—	15
21	37.5	22	30	33	20
22	39	13.5	31	34	22
23	39	12	31	34.5	22
24	41	10	32.5	36	23.5

LINE # E SPREAD LENGTH 250'

SPREAD LOCATION 0+0 → 2+50 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 0+0	HIGH END SHOT AT 2+50	CENTER SHOT AT 1+25	LOW QUARTER SHOT AT 0+65	HIGH QUARTER SHOT AT 1+85
1	10	36	21	15	37
2	—	36	19	—	36
3	13	35.5	—	14	35.5
4	14	—	18.5	12	—
5	12.5	35	15	9	—
6	17.5	34	—	9	34.5
7	15	—	14.5	7.5	—
8	15.5	—	14	11.5	32.5
9	18	—	12.5	13	30
10	17	33	—	14	—
11	—	—	10	—	—
12	23.5	—	7	—	33
13	23.5	—	8	18	31.5
14	—	—	10	21	30
15	24.5	29	—	22.5	29
16	25.5	28.5	16	24.5	26
17	29	—	—	26.5	21
18	32.5	27.5	—	30	12
19	32	—	27	30	11.5
20	33	27	27	30	14.5
21	33	—	27	30.5	24.5
22	33.5	24	28	32	33.5
23	35	15	29	31.5	35.5
24	36	9	30	—	37

LINE # E SPREAD LENGTH 250'

SPREAD LOCATION 2+50 → 5+0 NUMBER OF TRACES 24

Seismic travel times in milliseconds

#	LOW END SHOT AT 2+50	HIGH END SHOT AT 5+0	CENTER SHOT AT 3+75	LOW QUARTER SHOT AT 3+15	HIGH QUARTER SHOT AT 4+35
1	10.2	39.5	32.8	29.8	36.8
2	19.2	—	33.0	29.8	—
3	25.5	37.8	30.3	26.5	36.0
4	27.8	36.5	28.3	23.3	34.5
5	28.8	35.5	27.8	14.8	34.0
6	29.0	—	29.8	5.5	33.0
7	34.0	—	30.8	5.5	37.0
8	34.8	37.0	28.8	14.5	35.5
9	34.0	—	26.0	23.8	33.3
10	33.3	32.5	22.3	28.8	30.5
11	34.6	30.3	15.0	30.3	28.8
12	33.3	29.0	6.3	29.8	26.0
13	35.6	29.1	5.8	—	25.8
14	34.6	27.8	14.6	—	24.3
15	34.8	27.3	—	—	24.3
16	38.6	26.1	23.3	34.3	21.8
17	36.6	26.1	24.3	33.3	14.6
18	38.0	24.3	25.1	36.1	5.6
19	35.8	23.1	25.1	—	6.6
20	37.1	20.8	24.8	—	15.3
21	35.6	17.4	22.1	33.1	18.1
22	37.1	17.4	24.8	34.8	19.4
23	38.9	16.6	25.4	35.4	20.4
24	37.9	11.1	25.9	35.1	21.4

LINE # E SPREAD LENGTH 250'

SPREAD LOCATION 5+0 → 7+50 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 5+0	HIGH END SHOT AT 7+50	CENTER SHOT AT 6+25	LOW QUARTER SHOT AT 5+65	HIGH QUARTER SHOT AT 6+85
1	14.4	—	20.9	16.9	28.8
2	14.9	—	19.1	15.1	26.6
3	13.8	30.8	17.1	13.1	25.4
4	14.6	30.8	16.4	12.6	24.4
5	16.1	29.8	16.1	11.6	24.3
6	16.8	29.3	15.1	5.6	23.6
7	16.8	—	13.3	8.6	21.8
8	17.6	—	13.1	10.3	21.8
9	18.8	27.3	12.3	11.3	21.1
10	20.8	26.6	10.3	14.1	18.8
11	21.3	26.1	8.8	13.8	19.6
12	21.6	25.6	5.3	15.3	19.1
13	21.8	25.8	6.3	16.0	19.3
14	23.8	25.6	11.3	17.3	18.0
15	23.8	24.3	12.0	17.5	17.3
16	21.3	19.0	10.0	14.8	13.0
17	22.8	20.3	11.5	16.5	11.3
18	27.0	21.8	15.8	21.0	6.5
19	29.5	22.5	18.8	23.8	5.3
20	33.0	23.0	21.8	27.0	14.0
21	34.0	14.5	22.8	—	19.5
22	35.0	8.0	—	26.3	19.0
23	36.0	9.2	24.2	28.5	23.0
24	38.8	18	25.5	31	24.2

LINE # F SPREAD LENGTH 250'

SPREAD LOCATION 0+0 → 2+50 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 0+0	HIGH END SHOT AT 2+50	CENTER SHOT AT 1+25	LOW QUARTER SHOT AT 0+65	HIGH QUARTER SHOT AT 1+85
1	10.5	34.0	29.5	26.5	28.8
2	19.0	33.8	28.8	26.0	28.8
3	22.0	32.3	26.3	24.8	28.0
4	24.3	31.8	24.5	24.3	27.8
5	25.3	31.5	25.0	16.3	26.8
6	26.5	31.3	24.3	7.8	27.0
7	26.8	—	22.0	8.0	24.0
8	26.8	27.5	22.5	16.5	23.5
9	29.0	27.8	21.3	22.3	24.3
10	30.5	25.5	17.3	23.5	20.5
11	26.3	24.8	14.6	22.5	20.3
12	26.8	23.3	5.8	23.6	19.0
13	26.1	20.6	5.1	22.1	16.6
14	25.8	21.1	12.1	22.1	15.6
15	25.6	20.6	13.6	24.3	16.3
16	25.1	23.1	14.1	23.8	15.1
17	25.3	19.3	15.1	24.8	14.8
18	26.3	20.1	14.6	25.8	5.8
19	26.8	20.1	17.8	27.8	6.6
20	27.3	19.8	18.6	28.3	15.3
21	28.1	—	19.8	29.4	16.6
22	29.6	18.1	20.6	30.1	18.4
23	30.4	14.9	19.1	30.4	18.4
24	30.8	9.9	19.6	28.8	19.4

LINE # F SPREAD LENGTH 250'

SPREAD LOCATION 2+80 → 5+30 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 2+80	HIGH END SHOT AT 5+30	CENTER SHOT AT 4+05	LOW QUARTER SHOT AT 3+45	HIGH QUARTER SHOT AT 4+65
1	11.1	34.4	26.1	24.4	30.9
2	14.9	33.4	26.1	23.9	30.1
3	19.8	33.8	26.4	22.8	29.8
4	22.6	32.6	24.6	18.1	29.6
5	26.1	31.6	23.8	14.8	28.6
6	25.1	31.1	23.1	7.8	27.8
7	23.1	30.8	22.3	7.6	27.3
8	24.8	29.1	26.3	14.6	28.6
9	26.1	30.1	22.1	20.3	27.3
10	26.8	28.6	19.6	22.6	26.3
11	25.6	25.1	15.6	28.8	—
12	28.3	26.8	9.6	22.8	25.1
13	—	27.6	9.8	26.6	24.0
14	29.0	26.8	13.0	24.3	24.3
15	29.8	25.8	17.8	25.3	23.0
16	30.8	26.0	20.8	25.5	19.3
17	31.3	24.5	21.5	27.0	14.3
18	30.8	23.3	23.5	27.0	7.0
19	31.5	22.5	23.5	26.5	8.8
20	32.3	22.5	25.5	28.5	15.8
21	33.0	20.8	24.5	28.3	19.3
22	31.8	19.0	25.3	28.8	21.3
23	—	16.2	26.5	23.5	23.8
24	32	14.0	26.5	28.2	22.5

LINE # F SPREAD LENGTH 250'

SPREAD LOCATION 5+30 → 7+80 NUMBER OF TRACES 24

Seismic travel times in milliseconds

#	LOW END SHOT AT 5+30	HIGH END SHOT AT 7+80	CENTER SHOT AT 6+55	LOW QUARTER SHOT AT 5+90	HIGH QUARTER SHOT AT 7+15
1	12.5	32.2	21.5	18.0	26.2
2	15.8	33.0	20.5	17.2	24.0
3	16.3	33.8	20.8	17.5	26.8
4	19.3	34.0	20.5	19.0	27.5
5	20.3	34.5	21.0	11.0	—
6	22.3	33.5	20.3	4.0	26.5
7	20.8	31.3	19.5	7.3	25.5
8	23.8	34.5	21.3	17.0	—
9	24.8	33.5	19.3	19.5	24.3
10	24.3	32.0	17.8	19.3	24.3
11	25.0	30.8	14.6	19.8	21.0
12	24.8	29.6	9.0	20.3	21.8
13	25.3	26.8	6.6	20.6	20.8
14	27.1	29.1	12.3	21.3	20.8
15	27.8	27.1	16.1	22.1	20.6
16	27.8	27.1	17.8	22.6	16.3
17	31.6	24.8	17.6	26.6	15.3
18	30.3	25.6	17.1	27.8	6.6
19	31.3	26.1	22.6	26.3	9.3
20	29.1	23.6	20.8	—	14.6
21	31.8	25.8	20.1	27.4	21.4
22	33.1	25.1	21.6	28.8	22.8
23	32.6	20.8	24.6	28.9	24.4
24	35.8	15.1	26.6	30.6	24.4

LINE # 6 SPREAD LENGTH 250'

SPREAD LOCATION 0+0 → 2+50 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 0+0	HIGH END SHOT AT 2+50	CENTER SHOT AT 1+25	LOW QUARTER SHOT AT 0+65	HIGH QUARTER SHOT AT 1+85
1	9.0	27.8	23.0	19.8	30.0
2	12.5	31.0	25.8	20.0	29.2
3	13.5	32.3	26.5	20.8	30.8
4	16.0	30.3	27.3	16.0	30.0
5	18.5	34.3	28.0	12.8	31.5
6	20.8	34.3	—	4.0	32.5
7	21.8	32.3	26.5	5.0	31.3
8	22.8	32.3	25.8	13.5	30.5
9	24.3	32.5	25.5	21.3	29.5
10	25.0	32.3	15.3	21.8	29.5
11	25.6	29.8	12.8	26.0	27.8
12	26.6	28.3	4.6	26.6	26.6
13	26.1	26.8	4.8	25.8	22.6
14	26.8	27.8	13.6	26.8	22.6
15	26.8	24.8	17.3	27.3	16.1
16	27.8	25.1	20.3	26.6	10.6
17	28.8	25.6	22.8	25.1	9.6
18	29.8	25.1	25.1	30.6	4.3
19	30.6	24.6	26.3	32.8	5.3
20	31.3	24.8	27.6	33.1	10.3
21	33.1	23.6	29.4	34.4	11.6
22	34.6	18.6	30.6	35.4	15.4
23	35.4	17.4	30.4	46.1	16.6
24	36.1	8.6	35.9	49.4	16.6

LINE # 6 SPREAD LENGTH 250'

SPREAD LOCATION 2+50 → 5+0 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 2+50	HIGH END SHOT AT 5+0	CENTER SHOT AT 3+75	LOW QUARTER SHOT AT 3+15	HIGH QUARTER SHOT AT 4+35
1	8.4	53.1	26.1	20.8	39.4
2	17.4	51.4	24.9	20.4	37.6
3	18.1	44.8	22.1	21.1	33.6
4	17.4	44.4	21.1	15.4	31.8
5	18.8	42.8	21.1	13.6	30.6
6	20.1	44.8	20.3	4.6	29.1
7	25.1	43.8	18.8	4.3	29.6
8	20.8	32.8	16.3	13.3	27.1
9	20.3	28.1	14.6	15.3	16.8
10	28.6	22.3	12.3	16.1	13.3
11	19.3	19.8	10.3	14.8	14.3
12	21.6	20.6	6.1	17.6	14.6
13	22.0	23.8	5.8	18.8	12.8
14	31.6	20.8	10.6	19.8	11.8
15	25.3	20.3	14.0	21.0	14.8
16	24.8	21.3	15.3	23.0	13.3
17	24.8	19.3	14.3	20.3	12.8
18	27.3	18.3	14.8	30.0	5.5
19	28.5	19.8	19.5	29.3	4.5
20	30.0	18.3	16.3	33.0	13.5
21	27.0	17.5	14.3	31.0	14.0
22	30.5	15.5	19.0	34.0	14.5
23	29.8	15.2	20.0	35.8	15.8
24	30.2	11.5	20.0	37.0	17.0

LINE # H SPREAD LENGTH 250'

SPREAD LOCATION 2+50 → 5+0 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 2+50	HIGH END SHOT AT 5+0	CENTER SHOT AT 3+75	LOW QUARTER SHOT AT 3+15	HIGH QUARTER SHOT AT 4+35
1	8.9	39.1	29.1	21.1	33.1
2	14.1	34.9	26.1	19.1	31.6
3	16.1	32.8	23.8	17.1	30.1
4	18.1	31.6	24.6	15.4	29.4
5	20.6	31.8	23.8	12.8	28.8
6	20.1	31.3	22.6	4.3	27.3
7	20.8	29.6	21.8	4.6	26.6
8	21.1	29.8	20.8	13.3	26.1
9	24.1	29.6	18.8	16.6	25.6
10	24.8	29.1	15.1	18.3	24.8
11	25.3	27.8	8.3	18.8	23.8
12	24.6	27.1	3.8	20.1	23.1
13	26.0	25.6	5.6	20.0	20.6
14	26.0	24.8	11.6	21.0	18.6
15	28.3	24.0	15.8	22.3	17.0
16	27.3	23.0	17.5	22.3	14.0
17	28.3	21.5	18.5	23.3	12.3
18	30.0	22.0	21.5	25.0	3.8
19	32.5	21.0	23.3	25.8	5.3
20	32.8	19.0	24.8	27.3	14.3
21	33.5	18.0	25.0	26.3	16.0
22	33.0	15.0	25.5	27.8	17.3
23	34.0	14.0	26.8	29.0	18.8
24	35.2	12.2	27.5	28.8	20.5

LINE # H SPREAD LENGTH 250'

SPREAD LOCATION 5+50 → 8+0 NUMBER OF TRACES 24

Seismic travel times in milliseconds

#	LOW END SHOT AT 5+50	HIGH END SHOT AT 8+0	CENTER SHOT AT 6+75	LOW QUARTER SHOT AT 7+15	HIGH QUARTER SHOT AT 7+35
1	12.9	35.1	30.1	21.8	30.9
2	17.6	35.4	30.1	20.9	32.4
3	18.6	32.6	29.6	18.6	31.9
4	19.6	33.1	27.8	14.4	29.8
5	22.3	33.1	26.3	13.8	31.3
6	23.3	30.3	24.8	5.3	29.6
7	24.8	31.1	22.6	7.6	28.1
8	21.8	29.6	20.3	13.1	26.8
9	28.8	29.6	18.1	15.8	24.8
10	30.1	30.1	15.1	18.3	23.6
11	31.1	28.3	9.1	20.8	24.1
12	32.3	27.3	8.8	22.3	23.3
13	30.0	26.6	9.0	24.6	21.8
14	29.3	25.6	14.8	26.3	17.6
15	31.8	25.3	17.5	26.0	19.0
16	32.8	23.3	19.0	27.8	15.8
17	33.5	23.8	21.5	28.8	13.5
18	35.8	21.8	23.0	28.3	8.0
19	35.8	20.3	24.0	28.5	7.8
20	37.5	20.0	24.8	29.5	13.5
21	35.5	18.8	26.0	29.8	15.0
22	35.5	14.8	26.0	29.8	17.5
23	37.0	14.0	26.0	29.0	18.8
24	38.2	12.2	26.2	29.0	19.2

LINE # I SPREAD LENGTH 250'

SPREAD LOCATION 0+0 → 2+50 NUMBER OF TRACES 24

Seismic travel-times in milliseconds

#	LOW END SHOT AT 0+0	HIGH END SHOT AT 2+50	CENTER SHOT AT 1+25	LOW QUARTER SHOT AT 0+65	HIGH QUARTER SHOT AT 1+75
1	10.0	43.0	39.8	24.5	39.5
2	18.2	40.0	34.5	19.8	38.8
3	22.3	38.3	33.0	17.5	36.3
4	25.0	38.0	33.0	17.0	36.3
5	26.8	37.0	30.0	13.3	36.3
6	30.5	34.3	30.0	8.5	—
7	30.8	34.3	26.8	8.5	33.5
8	32.8	34.0	25.0	13.5	32.5
9	35.8	34.3	23.8	17.8	33.3
10	37.8	31.8	20.3	19.5	29.5
11	37.8	29.3	18.3	19.3	27.0
12	40.0	28.6	11.6	22.6	27.0
13	41.1	28.8	12.1	25.1	25.6
14	40.8	27.8	20.1	27.3	24.6
15	38.3	27.8	23.3	29.3	24.8
16	41.3	27.1	22.6	28.3	21.8
17	468	27.3	27.8	31.8	13.8
18	44.8	26.1	28.1	32.6	5.1
19	46.6	25.1	30.6	32.8	4.8
20	46.6	24.1	303	33.1	13.8
21	42.8	18.6	27.6	30.4	16.8
22	46.4	174	29.4	31.8	21.4
23	45.6	15.6	30.1	32.6	22.9
24	46.4	8.6	30.6	33.1	24.1

APPENDIX B

ELECTROMAGNETIC TERRAIN CONDUCTIVITY
METHOD OF INVESTIGATION

GENERAL CONSIDERATIONS

The electromagnetic terrain conductivity [EM] survey is a method of obtaining subsurface information through "remote" inductive electric measurements made at the surface of the earth. Although limited in application, the EM method has significant advantage in speed and definition for certain problems. The parameter measured with this technique is the apparent conductivity of the subsurface. The conductivity meter consists of receiver coil and a separate transmitter coil which induces an electrical source field [a circular eddy current loop] in the earth [Figure 1]. Each current loop generates a magnetic field proportional to the value of the current flowing within the loop. Part of the magnetic field from each current loop is intercepted by the receiver coil and converted to an output voltage which is linearly related to terrain conductivity. EM instrument readings are in millimhos per meter.

Geologic materials can be characterized by their electrical characteristics; lateral variations in conductivity values generally indicate a change in subsurface conditions. The relative conductivity of earth materials is particularly sensitive to water content and dissolved salts or ions. Accordingly, dry sands and gravels, and massive rock formations have low conductivity values; conversely, most clays and materials with a high ion content have high conductivity values.

FIELD PROCEDURE FOR DATA ACQUISITION

Weston Geophysical generally uses two common terrain conductivity meters: the Geonics EM-31 and the EM-34-3. The EM-31 has a fixed intercoil spacing of 3.7 meters and an effective depth of penetration of approximately 6 meters. The EM-34-3 has two coils which can be separated by 10, 20, or 40 meters and can be oriented in either the horizontal or vertical dipole modes. Intercoil separations increase the effective depth of investigation as shown below.

Intercoil Spacing [meters]	Depth of Investigation [meters] Horizontal Dipoles	Vertical Dipoles
10	7.5	15
20	15	30
40	30	60

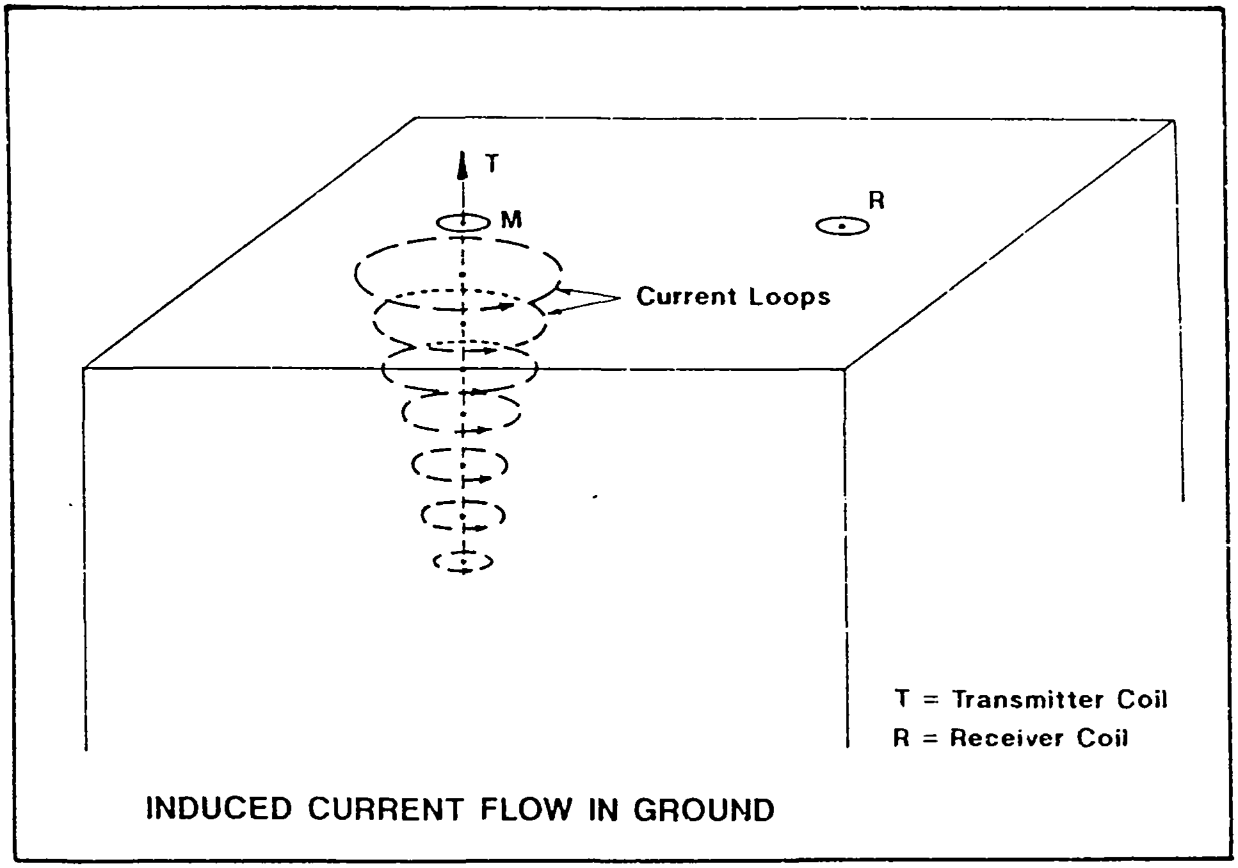
The coil orientation [horizontal or vertical] allows the EM-34-3 to respond to materials of different depths.

Conductivity measurements obtained with the EM-31 and/or the EM-34-3 can be obtained at any spacing along a survey line. EM-31 readings have the added flexibility of being recorded on a continuous chart recorder providing continuous data along a survey line.

DATA INTERPRETATION

EM data interpretation is generally subjective, that is measured EM values are contoured or profiled to identify high or low conductivity locations. Conductivity values obtained by an EM survey are relative values and depth estimates to conductive surface or bodies are best accomplished with an on-site calibration.

The EM-31 and EM-34-3 measure terrain conductivity in millimhos/meter. These values can be converted to resistivity [ohm/meters] for comparison with resistivity results by dividing the conductivity values into 1000.



Horizontal coplanar configuration (vertical dipole mode)

Figure 1

[illegible]
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EM 31
ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE 1

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
1+00	1.78	water		4+60	0.94		
1+50	0.96			4+66	1.14		
1+61	0.6			4+69	0.87		
1+67	1.17			4+75	1.28		
1+80	1.23			4+96	0.91		
1+90	r.p.	well		5+28	1.2		
1+98	1.21			5+53	1.14		
2+23	0.89			5+61	1.54		
2+[illegible]3	0.42			5+66	1.22		
2+[illegible]	0.82			5+75	1.57		
2+81	0.97			6+00	1.62		
2+92	0.78						
3+15	0.91						
3+[illegible]3	0.78						
3+50	1.02						
3+55	0.87						
3+85	0.90						
3+90	1.11						
4+09	1.17						
4+12	1.02						
4+25	1.32						
4+38	1.2						
4+50	1.28	damp					

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ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE 2

line 2

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
1+50	1.71	drilling station	near [illegible]	5+68	1.35		
1+82	0.93	swale ~	1+75	5+87	1.44		
2+00	2.16	piles		6+00	1.37		
2+07	0.39						
2+12	1.2						
2+24	0.58						
2+38	0.99						
2+66	0.9						
2+75	0.54			1+00	0.60		
2+80	1.05			1+0[illegible]	n.p.		
3+04	0.96			1+0[illegible]	n.p.		
3+07	0.72			1+0[illegible]	[illegible]		
3+30	1.14			[illegible]	[illegible]		
3+40	0.78			1+09	0.7[illegible]		
3+50	1.35	water		1+12	[illegible]		
4+16	1.53			1+15	n.p.		
4+47	1.14			1+20	n.p.		
4+57	1.42			[illegible]	1.76		
4+81	1.42	4+75-wet		[illegible]	0.44		
4+96	1.08			1+50	1.2	[illegible]	[illegible]
4+98	1.5						
5+35	1.73						
5+58	1.37	streamwater 5+5[illegible]					
5+63	1.58						

[illegible]
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ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE 4 & 3

line 4 | line 3

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00	0.81			—	1.8	Stream	
0+38	0.78			2+00	1.82		
0+41	r.p.			2+14	1.57		
0+52	r.p.	Line D (0+50)		2+37	2.17		
0+58	1.15			2+50	1.5		
0+66	0.51			2+63	1.32		
0+95	2.1			2+77	1.62		
1+13	1.28			2+95	1.26		
1+65	2.22	1+5 str		3+70	0.54		
1+79	1.65			4+08	0.98		
2+00	1.92			4+87	1.24		
2+03	1.65			5+08	1.5		
2+07	2.01			5+13	1.28	Stream	
2+15	1.8			5+36	1.55		
2+26	2.54			5+73	0.70		
2+38	2.1	Stream		5+82	0.90		
2+43	2.4			6+00	0.75		
2+70	1.06						
2+94	0.82						
3+00	1.14						

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ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE 6&5

line 6 | line5

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00	1.29			0+00	0.75		
0+35	1.08			0+35	0.78		
0+65	1.08			0+40	0.6		
0+70	1.26			0+93	0.84		
0+96	1.5			1+25	1.44		
1+00	1.26			1+81	0.92		
1+32	1.44			2+09	1.34	Metal pipe	
1+70	1.05			2+22	0.25		
~2+20	1.48	stream		2+45	1.70	stream	
2+50	1.14			2+80	0.87		
				3+00	0.87		

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EM 31
ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE 8

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
1+00	2.70	drill rig [illegible]	[illegible] 1+00	2+51	r.p.	5+00	[illegible]
1+[illegible]	2.16	drill		[illegible]	2.44	5+14	[illegible]
[illegible]	1.74			[illegible]	[illegible]	5+25	[illegible]
1+28	r.c.			[illegible]	2.61	[illegible]	[illegible]
1+30	r.p.			[illegible]	1.62	[illegible]	[illegible]
[illegible]	1.14			[illegible]	[illegible]	5+50	[illegible]
1+53	0.76			2+94	[illegible]		
[illegible]	1.14			[illegible]	[illegible]	0+00	1.5[illegible]
1+7[illegible]	0.48			3+10	.6[illegible]	[illegible]	1.[illegible]
[illegible]	0.75			3+25	1.65	[illegible]	r.p.
[illegible]	r.p.			[illegible]	1.2[illegible]	[illegible]	r.p.
2+0[illegible]	r.p.			[illegible]	1.2[illegible]	[illegible]	[illegible]
[illegible]	[illegible]			3+60	[illegible]	[illegible]	1.52
[illegible]	[illegible]			3+75	[illegible]	[illegible]	[illegible]
[illegible]	r.p.			[illegible]	[illegible].03	[illegible]	[illegible]
[illegible]	r.p.			[illegible]	[illegible]	[illegible]	r.p.
[illegible]	2.30			4+10	[illegible]		r.p.
[illegible]	r.p.			4+[illegible]	1.0[illegible]	[illegible]	[illegible]
[illegible]	r.p.			[illegible]	[illegible]	[illegible]	[illegible]
+225	[illegible].17			[illegible]	[illegible]	[illegible]	[illegible]
+23	r.p.			[illegible]	[illegible]	1+00	[illegible]
+26	[illegible]			4+50	[illegible]		
[illegible]	[illegible]			[illegible]	[illegible]	drill near	[illegible]
[illegible]	[illegible]						

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EM 31

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE 10 & 9

line 9 | line 10

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
3+00	0.96			1+00	3+		
2+86	0.7			1+14	1.76	[illegible]	
2+74	.99			1+25	[illegible].64		
2+58	.82			1+60	1.62		
2+25	.84			1+69	1.8		
2+17	.69			1+83	1.49		
1+88	0.9			2+05	1.23		
1+72	1.[illegible] (H	5[illegible] Stream		2+08	1.44	Stream	
1+54	0.9			2+16	1.44		
1+15	1.14			2+19	0.98		
1+07	0.99			2+50	0.99		
0+85	1.26			2+55	0.75		
0+63	1.23			2+68	1.17		
0+54	0.98			2+73	0.84		
0+42	1.46			2+85	0.90	0+50	r.p.
0+27	1.08			2+89	1.08	0+70	r.o
0+21	1.35			2+95	0.65	[illegible]73	3+
0+15	0.93			3+00	0.99	0+[illegible]	[illegible]
0+07	1.14					[illegible]	[illegible]
-0+23	1.06			-0+[illegible]	[illegible]		
-0+30	0.6			-0[illegible]	0.3[illegible]		
-0+41	1.02			-0+[illegible]	0.3[illegible]		
-0+50	0.10			[illegible]	1.04		
-1+00	0.62			[illegible]	0.7[illegible]		

metal

off scale

[illegible] 1.[illegible]
[illegible] [illegible]

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EM 31

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE 11

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+75	0.98						
0+84	0.15						
0+94	1.5						
1+10	0.84						
1+54	0.84						
1+59	1.05						
2+32	1.26						
2+40	1.44						
[illegible]	0.21						
2+61	1.17						
[illegible]	1.38						
3+15	0.85						
[illegible]	1.14						
3+60	0.91						
[illegible]	0.97						
[illegible]	1.17						
[illegible]	0.99						
[illegible]	1.23						
[illegible]	0.85						
[illegible]	1.17						
[illegible]	1.08						
[illegible]	1.66						
[illegible]	1.35						
5+25	2.07						

[illegible]
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ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE A

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00	0.90			4+48	1.56		
0+20	0.80			4+65	1.26		
0+32	1.21			5+27	2.35	~~4+3[illegible]~~ +[illegible]	~~1.86 hill~~ 1.39
0+55	0.69			5+35	1.95		
0+62	1.02			5+70	2.25		
0+95	0.72			5+76	1.92		
1+02	1.08			5+92	2.46		
1+30	0.78			5+98	2.1		
1+94	1.32	watre 1+50		6+09	3.06		
2+00	0.99			6+12	0.84	wells	
2+08	1.5			6+20	2.73	Stream	
2+25	1.2			6+31	2.36		
2+40	1.52	Water		6+42	2.68	metal pipe	
2+62	1.06			6+63	1.2		
2+70	1.2			7+00	0.73		
3+44	0.9			7+50	0.9		
3+55	1.17			8+00	0.96		
3+77	0.9						
4+00	1.06						
4+08	0.6						
4+15	1.23	Swale					
4+20	0.84						
4+37	1.65						
4+42	1.23						

[illegible]
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EM 31

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE D

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
1+00	2.76	[illegible]	[illegible]	6+15	2.07		
1+30	1.26			6+22	1.56		
1+45	2.43	Swale		6+74	1.3		
1+53	1.26			6+78	1.42		
1+66	1.15			6+85	1.16		
1+77	1.52			6+96	1.4		
1+82	0.48			7+15	1.18		
2+08	1.3			7+70	1.33		
2+50	0.96			7+97	1.14		
2+67	1.17			8+00	1.26		
2+75	0.99						
3+07	0.99			[illegible]	[illegible]		
4+08	1.56			[illegible]	[illegible]		
4+42	1.34			[illegible]	r.p.		
4+61	1.04			[illegible]	r.p.		
4+72	1.25			0+4[illegible]	1.7[illegible]	[illegible]	
4+85	1.08			0+5[illegible]	0.5[illegible]		
5+00	1.46			0+65	[illegible]		
5+06	1.28			[illegible]	r.p.		
5+19	1.52			[illegible]	r.p.		
5+27	1.65			[illegible]	[illegible]		
5+33	1.4			[illegible]	[illegible]		
5+66	1.74	5+50	1.69 [illegible]	1+00	2.[illegible]	[illegible]	[illegible]
5+70	1.53						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE A COIL SPACING 10 meter COIL ORIENTATION Horiz.

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00	1.2	6+00	2.0				
0+25	1.3	6+25	1.8				
0+50	1.6	6+50	1.3				
0+75	1.3	6+75	1.8				
1+00	1.2	7+00	1.2				
1+25	1.2	7+25	1.0				
1+50	1.5	7+50	1.1				
1+75	1.3	7+75	1.0				
2+00	1.2	8+00	1.0				
2+25	1.4						
2+50	1.1						
2+75	1.4						
3+00	1.3						
3+25	1.3						
3+50	1.1						
3+75	0.8						
4+00	0.5						
4+25	1.8						
4+50	1.5						
4+75	2.0						
5+00	3.0						
5+25	1.7						
5+50	1.9						
5+75	2.3						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE A COIL SPACING 10 meter COIL ORIENTATION Vertical

STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]
0+00	1.1	6+00	1.8				
0+25	1.4	6+25	1.4				
0+50	1.3	6+50	2.4				
0+75	1.0	6+75	1.2				
1+00	1.1	7+00	1.5				
1+25	1.3	7+25	1.0				
1+50	1.3	7+50	1.2				
1+75	1.4	7+75	1.2				
2+00	1.1	8+00	1.3				
2+25	0.9						
2+50	1.1						
2+75	1.0						
3+00	1.3						
3+25	1.2						
3+50	1.2						
3+75	1.4						
4+00	2.3						
4+25	2.3						
4+50	1.4						
4+75	1.6						
5+00	2.5						
5+25	2.0						
5+50	2.3						
5+75	2.0						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE B COIL SPACING 10 meter COIL ORIENTATION Horiz.

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00	0.9	6+00	1.1				
0+25	0.7	6+25	1.1				
0+50	0.8	6+50	1.9				
0+75	0.5	6+75	1.4				
1+00	0.9	7+00	1.4				
1+25	1.0	7+25	1.4				
1+50	1.3	7+50	1.6				
1+75	1.2	7+75	1.3				
2+00	1.2	8+00	0.9				
2+25	1.2						
2+50	1.1						
2+75	1.3						
3+00	1.8						
3+25	1.4						
3+50	1.0						
3+75	1.1						
4+00	1.1						
4+25	1.2						
4+50	1.0						
4+75	1.5						
5+00	1.2						
5+25	1.2						
5+50	1.3						
5+75	1.2						

EM 34
ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE B COIL SPACING 10 meter COIL ORIENTATION Vertical

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00	1.3	6+00	1.8				
0+25	1.2	6+25	2.3				
0+50	1.3	6+50	1.5				
0+75	1.0	6+75	1.1				
1+00	1.5	7+00	1.9				
1+25	1.6	7+25	1.0				
1+50	1.0	7+50	1.6				
1+75	2.2	7+75	0.7				
2+00	1.4	8+00	1.7				
2+25	2.4						
2+50	1.5						
2+75	1.4						
3+00	1.3						
3+25	1.7						
3+50	1.3						
3+75	1.4						
4+00	1.2						
4+25	1.8						
4+50	1.0						
4+75	2.0						
5+00	1.4						
5+25	1.3						
5+50	1.4						
5+75	0.9						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE C COIL SPACING 10meter COIL ORIENTATION Horiz

STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]
0+0	1.5	6+00	1.2				
0+25	1.9	6+25	1.5				
0+50	1.3	6+50	1.2				
0+75	1.6	6+75	1.2				
1+00	3.8	7+00	1.0				
1+25	3.4	7+25	0.9				
1+50	2.1	7+50	1.0				
1+75	1.9	7+75	0.9				
2+00	2.0	8+00	1.0				
2+25	2.4						
2+50	2.6						
2+75	2.1						
3+00	2.0						
3+25	2.3						
3+50	1.8						
3+75	2.0						
4+00	1.5						
4+25	1.3						
4+50	1.4						
4+75	1.4						
5+00	1.2						
5+25	1.4						
5+50	1.0						
5+75	1.0						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE C COIL SPACING 10meter COIL ORIENTATION Vert.

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+0	2.6	6+00	1.3				
0+25	1.3	6+25	1.0				
0+50	2.4	6+50	0.9				
0+75	2.1	6+75	1.6				
1+00	1.0	7+00	1.3				
1+25	2.2	7+25	0.8				
1+50	2.3	7+50	1.4				
1+75	1.9	7+75	1.0				
2+00	2.0	8+00	0.8				
2+25	1.9						
2+50	3.4						
2+75	3.3						
3+00	2.8						
3+25	2.0						
3+~~50~~ 60	1.8						
3+75	1.9						
4+00	2.9						
4+25	1.6						
4+50	1.2						
4+75	1.2						
5+00	1.1						
5+25	1.5						
5+50	1.5						
5+75	1.4						

EM 34
ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE D COIL SPACING 10 meter COIL ORIENTATION Horiz.

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00		6+00	1.7	12+00	1.5		
0+25	1.1	6+25	1.3				
0+50	1.2	6+50	1.4				
0+75	1.1	6+75	1.4				
1+00	2.0	7+00	1.6				
1+25	1.6	7+25	1.5				
1+50	1.0	7+50	1.3				
1+75	1.2	7+75	1.3				
2+00	1.1	8+00	1.8				
2+25	1.8	8+25	1.6				
2+50	1.4	8+50	1.0				
2+75	1.3	8+75	1.3				
3+00	1.2	9+00	1.0				
3+25	1.0	9+25	1.5				
3+50	0.9	9+50	1.8				
3+75	1.2	9+75	1.6				
4+00	1.8	10+00	1.8				
4+25	1.4	10+25	1.4				
4+50	1.3	10+50	1.4				
4+75	1.1	10+75	1.2				
5+00	1.0	11+00	1.8				
5+25	1.1	11+25	1.2				
5+50	1.7	11+50	1.6				
5+75	1.1	11+75	1.6				

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE D COIL SPACING 10 meter COIL ORIENTATION Vertical

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00		6+00	1.0	12+00	1.6		
0+25	3.3	6+25	2.4				
0+50	1.4	6+50	2.0				
0+75	1.4	6+75	2.0				
1+00	1.7	7+00	1.7				
1+25	1.5	7+25	2.0				
1+50	2.3	7+50	1.6				
1+75	1.8	7+75	2.0				
2+00	1.8	8+00	1.6				
2+25	1.9	8+25	1.8				
2+50	1.4	8+50	2.0				
2+75	1.6	8+75	1.6				
3+00	1.4	9+00	1.2				
3+25	1.4	9+25	1.3				
3+50	1.8	9+50	1.4				
3+75	1.3	9+75	1.3				
4+00	1.4	10+00	1.3				
4+25	1.8	10+25	1.5				
4+50	2.4	10+50	1.5				
4+75	2.0	10+75	1.7				
5+00	1.4	11+00	1.3				
5+25	1.6	11+25	1.5				
5+50	2.0	11+50	2.0				
5+75	1.4	11+75	1.6				

EM 34
ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE E COIL SPACING 10 meter COIL ORIENTATION Horizontal

STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]
0+0	1.8	6+00	3.1				
0+25	1.6	6+25	1.7				
0+50	1.3	6+50	1.5				
0+75	1.5	6+75	1.7				
1+00	1.65	7+00	1.7				
1+25	1.7	7+25	1.6				
1+50	2.0	7+50	1.5				
1+75	2.1						
2+00	2.4						
2+25	2.4						
2+50	2.7						
2+75	2.8						
3+00	3.1						
3+25	3.3						
3+50	4.1						
3+75	2.4						
4+00	3.0						
4+25	3.0						
4+50	3.2						
4+75	2.2						
5+00	1.6						
5+25	1.4						
5+50	1.4						
5+75	1.8						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE E COIL SPACING 10 meter COIL ORIENTATION Vertical

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+0	1.0	6+0	1.8				
0+25	1.45	6+25	2.0				
0+50	1.25	6+50	2.0				
0+75	1.3	6+75	1.3				
1+00	2.1	7+00	1.5				
1+25	2.1	7+25	1.7				
1+50	3.1	7+50	1.1				
1+75	3.2						
2+00	3.2						
2+25	3.9						
2+50	3.6						
2+75	3.2						
3+00	2.9						
3+25	2.4						
3+50	2.4						
3+75	-0.75	← Culvert					
4+00	3.3						
4+25	1.9						
4+50	2.1						
4+75	1.5						
5+00	2.3						
5+25	2.0						
5+50	1.7						
5+75	1.6						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE F COIL SPACING 10meter COIL ORIENTATION Horiz

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00	2.5						
0+25	2.5						
0+50	3.0						
0+75	3.0						
1+00	2.2						
1+25	1.9						
1+50	1.6						
1+75	1.6						
2+00	1.8						
2+25	1.8						
2+50	2.0						
2+75	1.8						
3+00	1.6						
3+25	1.3						
3+50	1.7						
3+75	1.9						
4+00	2.1						
4+25	2.4						
4+50	2.8						
4+75	2.8						
5+00	3.3						
5+25	4.6						
5+50	5.8						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE F COIL SPACING 10meter COIL ORIENTATION Vert

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
0+00	4.0						
0+25	3.0						
0+50	2.1						
0+75	1.8						
1+00	2.0						
1+25	2.7						
1+50	2.4						
1+75	2.4						
2+00	2.2						
2+25	2.4						
2+50	2.0						
2+75	2.1						
3+00	2.4						
3+25	2.0						
3+50	3.0						
3+75	2.8						
4+00	2.7						
4+25	2.9						
4+50	3.0						
4+75	3.8						
5+00	4.0						
5+25	3.9						
5+50	4.7						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE G COIL SPACING 10 meter COIL ORIENTATION Horiz.

STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]
0+50	1.8						
0+75	1.7						
1+00	2.0						
1+25	2.1						
1+50	2.0						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE G COIL SPACING 10 meter COIL ORIENTATION Vertical

STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]	STATION	READINGS [mmhos/m]
0+50	3.4						
0+75	2.5						
1+00	3.6						
1+25	3.8						
1+50	4.2						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE H COIL SPACING 10 meter COIL ORIENTATION Horiz.

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
5+75	2.6						
6+00	2.4						
6+25	2.4						
6+50	2.1						
6+75	2.2						
7+00	2.3						
7+25	2.4						
7+50	2.5						
7+75	3.6						
8+00	5.4						
8+25	5:6						
8+50	3.9						

EM 34

ELECTROMAGNETIC TERRAIN CONDUCTIVITY DATA

LINE H COIL SPACING 10 meter COIL ORIENTATION Vertical

STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)	STATION	READINGS (mmhos/m)
5+75	3.2						
6+00	2.2						
6+25	3.3						
6+50	2.8						
6+75	3.3						
7+00	3.0						
7+25	3.6						
7+50	3.5						
7+75	2.4						
8+00	1.4						
8+25	2.6						
8+50	-1.1						

APPENDIX C

MAGNETOMETER [TOTAL FIELD] MEASUREMENTS
FOR DETECTION OF BURIED METAL OBJECTS
METHOD OF INVESTIGATION

INTRODUCTION

The magnetic method is a versatile, relatively inexpensive, geophysical exploration technique. Aeromagnetic surveys and deep water marine studies are commonly used as a reconnaissance tool for tracing large-scale geologic structure. Land and coastal water marine data are more useful in tracing smaller, more localized geologic structures, such as mineral and ore deposits. Land and marine surveys yield more detail and higher resolution, since the measurements are taken closer to the anomaly source. Land and shallow water magnetic data is commonly used to locate larger buried, man-made objects such as pipelines, barrels or other buried metal objects, and smaller objects such as involved in archaeological prospecting.

EARTH MAGNETISM

Magnetics is a "potential field" method. For a given magnetic field, the magnetic force in a given direction is equal to the derivative of the magnetic potential in that direction. The source of the earth's magnetic potential is its own magnetic field and the induction effect this field has on magnetic objects or bodies above and below the surface. The earth's field is a vector quantity having a unique magnitude and d[illegible] at every point on the earth's surface. This magnetic field is defined in three dimensions by angular quantities known as declination and inclination. Declination is defined as the angle between geographic north and magnetic north, and inclination is the angle between the direction of the earth's field and the horizontal [Figure 1]. The earth's magnetic field is measured in "gammas" [where 1 gamma = 10^{-5} Oersted]; the total field ranges from about 25,000 gammas near the equator to 70,000 gammas near the poles.

The earth's magnetic field is not completely stable. It undergoes long-term [secular] variations over centuries; small, daily [diurnal] variations [less than 1% of the total field magnitude]; and transient fluctuations called magnetic storms resulting from solar flare phenomena.

The earth's ambient magnetic field is modified locally by both naturally-occurring and man-made magnetic materials. Iron or steel objects act as "local" dipoles, which are generally oriented differently than the earth's external magnetic field.

The iron or steel objects represents a local perturbation in the main earth field. The net field in the vicinity of this perturbation is simply the vector sum of the induced and earth fields. Thus, the induced field is a function of the "susceptibility" of the material, or its ability to act like a magnet.

Remanent magnetization is produced in materials which have been heated above the Curie point allowing magnetic minerals in the material to become aligned with the earth's field before cooling. The remanent field direction is not always parallel to the earth's present field, and can often be completely reversed. The remanent field combines vectorially with the ambient and induced field components. The contribution of the remanent components must be considered in magnetic interpretations.

INSTRUMENTATION

At present, the most widely used magnetometer is the "proton precession" type. This device utilizes the precession of spinning protons of the hydrogen atoms in a sample of fluid [kerosene, alcohol, or water] to measure total magnetic field intensity.

Protons spinning in an atomic nucleus behave like magnetic dipoles, which are aligned [polarized] in a uniform magnetic field. The protons initially aligned themselves parallel to the earth's field. A second, much stronger magnetic field is produced approximately perpendicular to the earth's field by introducing currents through a coil of wire. The protons become temporarily aligned with this stronger secondary field. When this secondary field is removed, the protons tend to realign [precess] themselves parallel to the earth's field direction. The precessing protons will generate a small electric signal in the same coil used to polarize them with a frequency [about

2,000 Hz] proportional to the total magnetic field intensity but independent of the coil orientation. By measuring the signal frequency, the absolute value of the total earth field intensity can be obtained to a 1 gamma accuracy. The total magnetic field value measured by the proton precession magnetometer is the net vector sum of the ambient earth's field and any local induced and/or remanent perturbations.

A total field proton precession magnetometer can be made portable and does not require orientation or leveling. There are a few limitations associated with the precession system. The precession signal can be severely degraded in the presence of large field gradients [greater than 200 gammas per foot] near 60-cycle A/C power lines. Also, the interpretation of total field data is sometimes more complicated than vertical field data which, however, is more time consuming to take.

FIELD TECHNIQUES

The field operator must avoid or note any sources of high magnetic gradients and alternating currents, such as power lines, buildings, and any large iron or steel objects. Readings are taken at a predetermined interval which depends on the nature of the survey, the accuracy required, and the gradients encountered. Base station readings, if required, are usually made several times a day to check for diurnal variations and magnetic storms.

INTERPRETATION

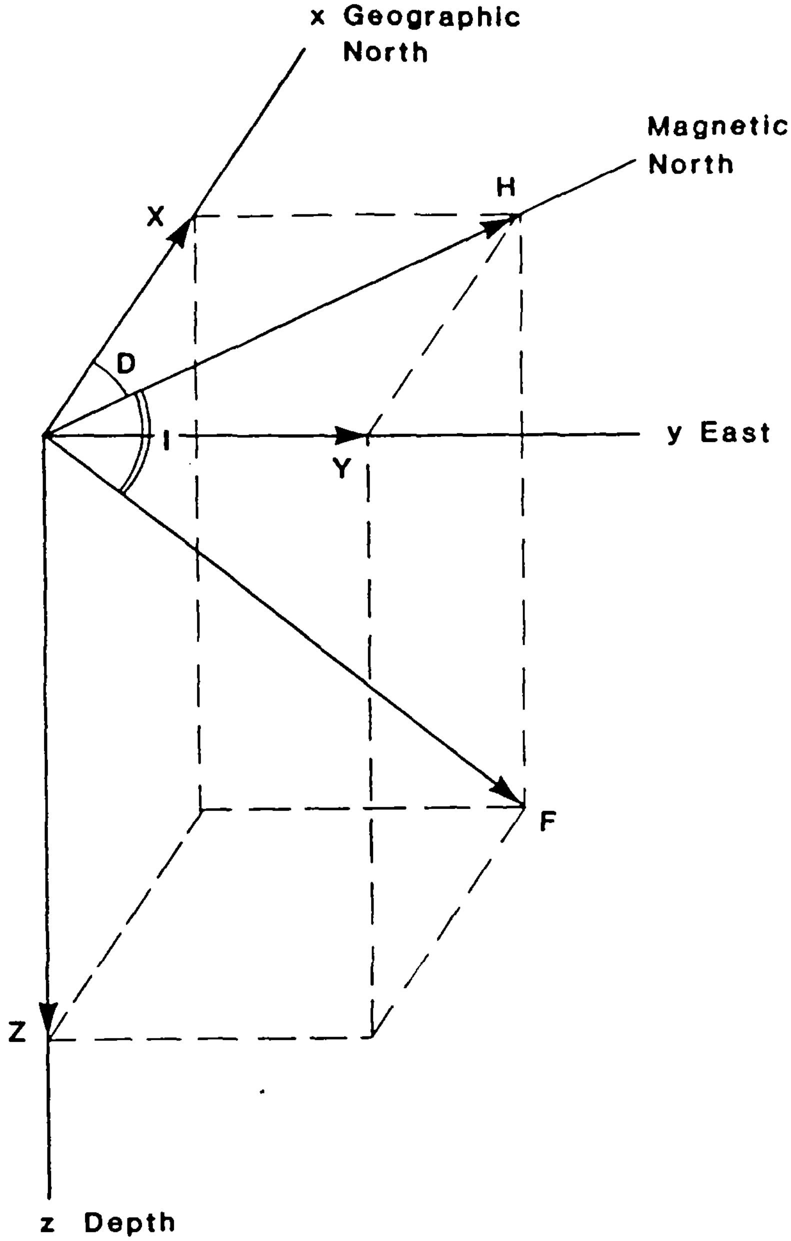
Lateral variations in susceptibility and/or remanent magnetization in crustal rocks give rise to localized anomalies in the measured total magnetic field intensity. Geologic structural features [faults, contacts, intrusions, etc.] and metal objects will cause magnetic anomalies, which can be interpreted to define the location of the causative source.

After diurnal effects and regional gradients have been removed, magnetic anomalies can be studied in detail with derivative operations and frequency filtering employed to define depth and shape.

Because it is a potential field method, there are a number of possible source configurations for any given magnetic anomaly. There is also an inherent complexity in magnetic dipole behavior. If the various magnetic field parameters [inclination, declination, and susceptibility] are well defined, and some reasonable assumptions can be made regarding the nature of the source, an accurate source model can generally be derived.

Magnetic anomalies can be analyzed both qualitatively and quantitatively. The physical dimensions of an anomaly [slope, wave-length, amplitude, etc.] often reveal enough to draw some general qualitative conclusions regarding the location and depth of the causative source.

Precise interpretation must be done quantitatively and requires prior knowledge of earth and remanent magnetic field parameters. Modeling can be performed by various approximation methods, whereby one reduces the source to a system of poles or dipoles, or assumes it to be one of several simple, geometric forms [vertical prism, horizontal slab, step, etc.]. The magnetic properties for this simplified model can be rather easily defined mathematically. Simple formulas can be derived which relate readily measurable anomaly parameters, such as slope, width, and amplitude ratios, to the general dimensions of the anomaly source, including depth to top, thickness, dip, and width normal to strike. Since these methods involve very limiting geometric assumptions, the results can be treated as good approximations only for very simplified sources.



I = Inclination

D = Declination

H = Horizontal Field Strength

F = Total Magnetic Force

ELEMENTS OF THE EARTH'S MAGNETIC FIELD

FIGURE 1

MAGNETIC DATA

JOB 16548-03 CLIENT Balsam Environmental LOCATION Mottolo Site

LINE A

STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)
3+50	55401	4+90	55638	6+60	55538		
3+60	55411	4+95	55628	6+70	55465		
3+70	55420	5+00	55504	6+80	55453		
3+80	55435	5+10	55415	6+90	55445		
3+90	55430	5+20	55408	7+00	55443		
4+00	55414	5+30	55407	7+10	55436		
4+10	55421	5+40	55400	7+20	55431		
4+15	55446	5+50	55394	7+30	55429		
4+20	55450	5+60	55385	7+40	55434		
4+30	55443	5+70	55381	7+50	55435		
4+40	55440	5+80	55379	7+60	55429		
4+50	55438	5+90	55388	7+70	55429		
4+60	55442	6+00	55427	7+80	55435		
4+65	55448	6+10	±5 55900	7+90	55447		
4+70	55469	6+20	±8 55884	8+00	55461		
4+75	55512	6+30	55394				
4+80	55548	6+40	±5 55492				
4+85	55548	6+50	±30 57140				

Weston Geophysical

MAGNETIC DATA

JOB 16548-03 CLIENT Balsam Environ. LOCATION McHole Site

LINE B

STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)
1+50	55461	3+30	55423	4+55	55512		
1+60	55455	3+40	55421	4+60	55497		
1+70	55450	3+50	55420	4+65	55484		
1+80	55446	3+60	55417	4+70	55477		
1+90	55454	3+70	55418	4+75	—		
2+00	55457	3+80	55416	4+80	55473		
2+10	55457	3+90	55413	4+90	55472		
2+20	55457	4+00	55413	5+00	55470		
2+30	55455	4+05	55416	5+10	55473		
2+40	55445	4+10	55416	5+20	55475		
2+50	55434	4+15	55423	5+30	55476		
2+60	55435	4+20	55434	5+40	55475		
2+70	55430	4+25	55461	5+50	55482		
2+80	55423	4+30	55495				
2+90	55421	4+35	55527				
3+00	55419	4+40	55549				
3+10	55419	4+45	55542				
3+20	55422	4+50	55542				

MAGNETIC DATA

JOB 16548-03 CLIENT Balsam Environmental LOCATION McHolo Site

LINE C

STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)
0+00	55498	1+80	55473	6+40	55445		
0+10	55565	1+90	55469	6+50	55442		
0+20	55505	2+00	55464	6+60	55450		
0+30	55500			6+65	55443		
0+40	55504	5+0	55475	6+70	55440		
0+50	55515	5+10	55482	6+80	55438		
0+60	55523	5+20	55491	6+90	55439		
0+70	55527	5+30	55495	7+00	55452		
0+80	55518	5+40	55493				
0+90	55512	5+50	55489				
1+00	55507	5+60	55480	4+50	55481		
1+10	55504	5+70	55450	4+60	55484		
1+20	55497	5+80	55479	4+70	55491		
1+30	55484	5+90	55479	4+80	55486		
1+40	55477	6+00	55472	4+90	55479		
1+50	55474	6+10	55466				
1+60	55470	6+20	55471				
1+70	55473	6+30	55461				

MAGNETIC DATA

JOB 16548-03 CLIENT Balsam Environmental LOCATION Mottolo Site

LINE D

STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)
4+00	55467	5+80	55441				
4+10	55544	5+90	55446				
4+20	55599	6+00	55447				
4+30	55572	6+10	55444				
4+40	55536	6+20	55439				
4+50	55521	6+30	55437				
4+60	55506	6+40	55435				
4+70	55496	6+50	55433				
4+80	55490	6+60	55437				
4+90	55477	6+70	55441				
5+00	55465	6+80	55448				
5+10	55460	6+90	55453				
5+20	55463	7+00	55457				
5+30	55461						
5+40	55459						
5+50	55454						
5+60	55447						
5+70	55441						

MAGNETIC DATA

JOB 16548-03 CLIENT Balsam Environmental LOCATION Mattole Site

LINE H

STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)	STATION	READINGS (gammas)
7+00	55453	8+80	55551				
7+10	55451	8+90	55474				
7+20	55451	9+00	55451				
7+30	55451						
7+40	55449						
7+50	55445						
7+60	55442						
7+70	55440						
7+80	55437						
7+90	55434						
8+00	55434						
8+10	55432						
8+20	55431						
8+30	55426						
8+40	55421						
8+50	55426						
8+60	55562						
8+70	55733						

APPENDIX B-2

HAGER-RICHTER GEOSCIENCE, INC. REPORT
SEPTEMBER 1989

(4024)

HAGER-RICHTER
GEOSCIENCE, INC.

SEISMIC REFRACTION SURVEY
MOTTOLO SUPERFUND SITE
RAYMOND, NEW HAMPSHIRE

Prepared for:

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59 Stiles Road
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Prepared by:

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File 89G32
September, 1989

Seismic Refraction Survey
Mottolo Superfund Site
Raymond, NH File 89G32

0. EXECUTIVE SUMMARY

Hager-Richter Geoscience, Inc. conducted a seismic refraction survey at the Mottolo Superfund Site, Raymond, Rockingham County, New Hampshire in September, 1989. The survey was conducted for Balsam Environmental Consultants, Inc. of Salem, New Hampshire as part of a larger RI/FS undertaken under the supervision of the USEPA.

The survey area is a wooded lot located on property adjacent to, and immediately south of, the Mottolo Site property line. The purpose of the seismic refraction survey was to provide information about the depth to bedrock and, if possible, the configuration of the bedrock surface.

The seismic refraction survey consisted of 4 lines of profile totaling 770 linear feet. A preliminary interpretation of the seismic data was made to provide information to help determine locations for two borings in the area. A two layer model best fit the seismic data; the model consisted of (1) a low velocity (1000-1500 fps) layer, interpreted to be unsaturated sediments, and (2) a high velocity layer (11,000-16,000 fps) interpreted to be bedrock.

The two borings, located along line SL1 on the basis of the preliminary seismic interpretation, encountered the groundwater table at one foot and 8 feet, respectively, above the bedrock surface which was at a depth of approximately 11 feet in both borings.

Taking into account the later boring information, the seismic data were reinterpreted assuming that a saturated layer exists between the upper low velocity layer and bedrock. Based on the reinterpretation, we conclude that three layers are likely present in the western half of the survey area. In the eastern half of the survey area, however, the water table is at or very near the bedrock surface and cannot be detected in the seismic data. The bedrock is generally 5 to 10 feet shallower in areas of higher surface elevation. Thus, the small ovoid hill to the south of the seismic survey lines may be bedrock controlled.

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TABLES, FIGURES AND PLATES

****

1. INTRODUCTION

Hager-Richter Geoscience, Inc. conducted a seismic refraction survey at the Mottolo Superfund Site, Raymond, Rockingham County, New Hampshire in September, 1989 for Balsam Environmental Consultants, Inc. of Salem, New Hampshire. The geophysical survey was part of a larger RI/FS project undertaken by Balsam under the supervision of the U.S. Environmental Protection Agency. The general location of the Site is shown in Figure 1.

The Mottolo Site is located in a semi-rural, wooded area. The area of the seismic refraction survey is a wooded lot immediately south of the Mottolo Site property line. The ground surface is generally level except for a small ovoid hill about 25 feet high in the south central part of the survey area.

The objective of the seismic refraction survey was to determine depth to bedrock and, if possible, configuration of the bedrock surface to assist Balsam in siting additional monitoring wells.

Hager-Richter personnel were on Site on September 12, 1989. Jeffrey Reid and George Fields conducted the seismic refraction survey. The field operations were coordinated with Mr. Timothy Stone of Balsam. Ms. Mindy Jacobs of Balsam specified the locations of all seismic refraction lines and observed the field work. The data were analyzed at our offices in Salem, New Hampshire. Original data and field notes reside in the Hager-Richter files and will be retained for a minimum of five years. Preliminary results were provided to Balsam on September 15 for use in siting additional wells.

2. EQUIPMENT AND PROCEDURES

For the seismic refraction survey, we used an EG&G Model ES1225 Multiple Channel Signal Enhancement Seismograph, a 110-foot spread cable, and twelve vertical geophones. The spacing between geophones was 10 feet.

The ES1225 is a microprocessor controlled instrument that allows seismic signals from several successive shots to be accumulated, or "stacked," and added selectively to the 12 channels in order to increase the signal-to-noise ratio. The field data were recorded both on permanent paper seismograms and on digital cassette by a portable digital recorder.

Energy for the seismic refraction survey was provided by hitting a steel baseplate with a 10-pound sledgehammer. The seismograph recorded data for 100 milliseconds after each shot.

Six shots (or "drops") were made for each geophone spread. Shots were made at both ends of the cable, 60 feet offset from each end of the cable, and at locations 30 feet and 80 feet along the spread cable. This procedure provides reversed refraction profiles for all segments. For the profiles longer than the 110-foot spread cable, the end shot point of each segment was reoccupied as the first shot point of the next segment. This procedure provides data redundancy and acts as a quality control measure.

The seismic data were analyzed using the Generalized Reciprocal Method (GRM) of seismic refraction interpretation (Palmer, 1980). The GRM has several advantages over other seismic refraction interpretation methods such as the crossover-distance method. The GRM allows for some variation in the surface topography as well as lateral variation in the seismic velocity of the upper layers. The method uses a principle of migration whereby the refractor need only be planar over a short distance, thus allowing the calculation of depth to an undulating interface. In addition, the GRM method is relatively insensitive to dip angles as high as 20^{o}, unlike most other methods which can be sensitive to dips as low as 5^{o}. The GRM also allows for the calculation of depth below each geophone instead of below only the shot points as in the Time-Intercept and Crossover Distance methods.

The calculated results were used to construct an interpreted velocity profile of the subsurface for each seismic line. The velocities of seismic waves are strong functions of the types of geologic material through which they pass. Table 1 lists the correlation of velocities to geologic materials expected at this Site. One can thus infer the subsurface stratigraphy from the velocities exhibited.

With the seismic refraction method, one cannot detect layers of lower velocity material underlying higher velocity material, a common situation in stratified sediments. If present, the "hidden" lower velocity layers cause an error in the thickness calculated for the upper layer. The uncertainty in depth estimates due to this and other causes may be +/- 10% or 1 foot, whichever is larger.

3. RESULTS AND DISCUSSION

3.1 General

The locations of the seismic refraction lines are shown in Plate 1. Data were obtained along 4 lines of profile for a total distance of 770 linear feet. The locations of all lines were specified in the field by the Balsam site representative. Seismic lines SL1 and SL2 are oriented approximately east-west and parallel to the Site property line. Seismic line SL1 is 330 feet long and located on the property line; SL2 is 220 feet long and is located about 100 feet south of the line. Seismic lines SL3 and SL4 are each 110 feet long, are oriented generally north-south, and intersect the other two lines. Surface elevations along each seismic line were estimated from the topographic map of the Site provided by Balsam and the precision is probably +/- 1 foot. Conditions at the Site were relatively quiet; and the quality of the seismic signals was judged to be good to very good. The seismic refraction first break arrival times are included as an appendix to this report.

The seismic data were interpreted in two stages. First, using only the seismic data, we produced preliminary profiles for Balsam shortly after the field work was completed. Second, after two borings were drilled along seismic line SL1, we reinterpreted the seismic data using the data obtained from those borings.

3.2 Initial Interpretation

Plates 2 and 3 show the preliminary interpreted profiles for each seismic line. The locations of intersecting seismic lines and the velocity range (in feet per second) exhibited by each layer are also indicated in the profiles. The seismic data were best fit by a simple two-layer model. The upper layer, with velocity ranging from 1000 fps to 1450 fps, was interpreted to be unsaturated sediments 6 to 11 feet thick. The lower layer, with velocity varying from 12500 fps to 15500 fps, was interpreted to be bedrock. We did not recognize a distinct layer with an intermediate velocity typical of saturated sediments in the seismic refraction data. The seismic refraction profiles were sent as a preliminary interpretation to Balsam in mid-September.

3.3 Re-interpretation of the Seismic Data

Based on the seismic results, two borings were drilled near line SL1. Boring MW-21D, located at 2+80 along line SL1, encountered the water table at approximately 10 feet below the ground surface and bedrock at about one foot below the water table. The seismic results for that location predicted 11 feet of low velocity material overlying bedrock (Plate 2). A water table one foot above the bedrock is not detectable on the basis of the seismic refraction data. A second boring MW-20S, located at 0+80 along line SL1, encountered the water table at 3 to 4 feet depth and bedrock at 11 to 12 feet below the ground surface. This result differed significantly from the preliminary seismic interpretation which estimated the bedrock depth to be six feet, with six feet of low velocity unsaturated material above bedrock.

At the request of Mr. Timothy Stone, we re-interpreted the seismic data in an attempt to answer the following questions:

1 Why was there no evidence of a water table in the seismic data?

2 Why was bedrock encountered five to six feet deeper than predicted in boring MW-20S?

A previous seismic refraction survey in the general area had been interpreted by Weston Geophysical on the basis of three different near-surface geologic models for the Mottolo site: 1) areas with only unsaturated sediments above the bedrock, 2) areas with only saturated sediments overlying bedrock and, 3) areas with unsaturated sediments overlying at least 10 feet of saturated sediments on top of bedrock. The seismic data acquired in this survey were well fit by the simple model of unsaturated sediments overlying bedrock. In addition, velocities indicative of saturated sand (4600-5000 fps) were not observed in the seismic data. Therefore, the original interpretation was based on a two layer model. Using models of seismic refraction arrival times based on the borehole logs leads to the following conclusions:

1 In order to identify with high confidence a water table refraction in seismic data in cases where the depth to the water table is 2-8 feet and the depth to bedrock is 10-12 feet, a geophone spacing of three feet or less must be used.

2 The predicted depth to bedrock at such shallow depths (less than 20 feet) is highly sensitive to the water table depth (e.g., a one-half foot error in the water table depth could result in a three foot error in bedrock depth).

Seismic line SL1 was re-interpreted using a three layer model which consisted of a low velocity surface layer, a saturated sand layer (i.e., water table), and bedrock. Depth to the water table was known at the boring locations and was estimated along the line by assuming that the first break arrival times of geophones 20 feet from the shots are from rays traveling along the water table. Knowing the velocity of the top layer and assuming a velocity of 4600 fps (Redpath, 1973) for the saturated sand layer, one can estimate the depth to the water table. The water table was assumed to be relatively horizontal. The result is shown in Plate 4. The insertion of a shallow water table in the model at the west end of the line increases the velocity of the overlying sediments and thus increases the bedrock depths from 2 to 10 feet. Thus, in the re-interpreted line the seismic bedrock depth matches that in boring MW-20S. At the east end of line SL1, the water table in boring MW-21D was found to be within one foot of bedrock. Because a one foot thick saturated layer above bedrock is not detectable in the seismic data, we show the water table as a dashed line just above the bedrock surface at this end of the line.

Reinterpretations of seismic lines SL2 and SL4, using a three layer model and the assumptions discussed above, are shown in Plate 5. The reinterpreted line SL4 shows an increase in bedrock depth from approximately 10 feet at the north end of the line to approximately 15 feet at the south end. Line SL2 shows a shallowing of the bedrock from approximately 13 feet depth at the west end to the line to about 10 foot depth at the east end of the line. The water table is approximately four feet deep at the western end of the line and is probably very near or at the bedrock surface at the eastern end of the line.

Seismic line SL3 is located along a topographic high and intersects the eastern ends of lines SL2 and SL4. Based on the information from boring MW-21D and our reinterpretation of lines SL2 and SL4, we infer that the water table along SL3 is within 1 foot of the bedrock surface or at the bedrock surface. Thus, since the three layer model for this line is essentially identical to the two layer model we do not plot it as a separate figure.

4. CONCLUSIONS

Based on the seismic refraction survey conducted on September 12, 1989 and information from borings MW-21D and MW-20S at the Mottolo Superfund Site in Raymond, New Hampshire, we conclude:

1. There are generally three layers present at the Site: (1) a low velocity (1000-1500 fps) layer interpreted to be unsaturated sediments, (2) A layer of saturated sands with an assumed velocity of approximately 4600 fps, and (3) a high velocity (11,000-16,000 fps) layer interpreted to be bedrock.

2. All three layers are likely present in the western half of the survey area. In the eastern half of the survey area, however, the water table is at or very near the bedrock surface and the saturated sand layer cannot be detected from seismic refraction data obtained with a geophone spacing of 10 feet.

3. The bedrock is generally 5 to 10 feet shallower in areas of higher surface elevation. The small ovoid hill to the south of the seismic survey lines may be bedrock controlled.

4. Due to the shallow bedrock depths in the survey area, water table depth variations such as found in the borings would not have been detectable by the seismic refraction survey with a geophone spacing of 10 feet. In order to identify with high confidence a water table refraction and detect changes in the water table, a refraction survey with geophone spacings of three feet or less would be required.

5. REFERENCES

Palmer, Derecke, The Generalized Reciprocal Method of Seismic Refraction Interpretation, Society of Exploration Geophysicists, Tulsa, Oklahoma, 1980, 104p.

Redpath, Bruce B., Seismic Refraction Exploration for Engineering Site Investigations, Defense Documentation Center, Alexandria, VA, 1973, 51p.

TABLE 1. RELATIONSHIP BETWEEN VELOCITY OF SEISMIC WAVES AND GEOLOGIC MATERIALS EXPECTED AT THE MOTTOLO SUPERFUND SITE

VELOCITY (Ft/Sec)	TYPE OF MATERIAL
1000-1700	Soft & uncompacted low-density materials including fill, unsaturated silt, sand, gravel and cobbles. May also include random boulders. Permeable.
4600-7000	Materials of the types above, but saturated with ground water. The ground water table is generally found at or near the upper surface of zones having this velocity range.
>11,000	Bedrock.

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Seismic Refraction Survey
Mottolo Superfund Site
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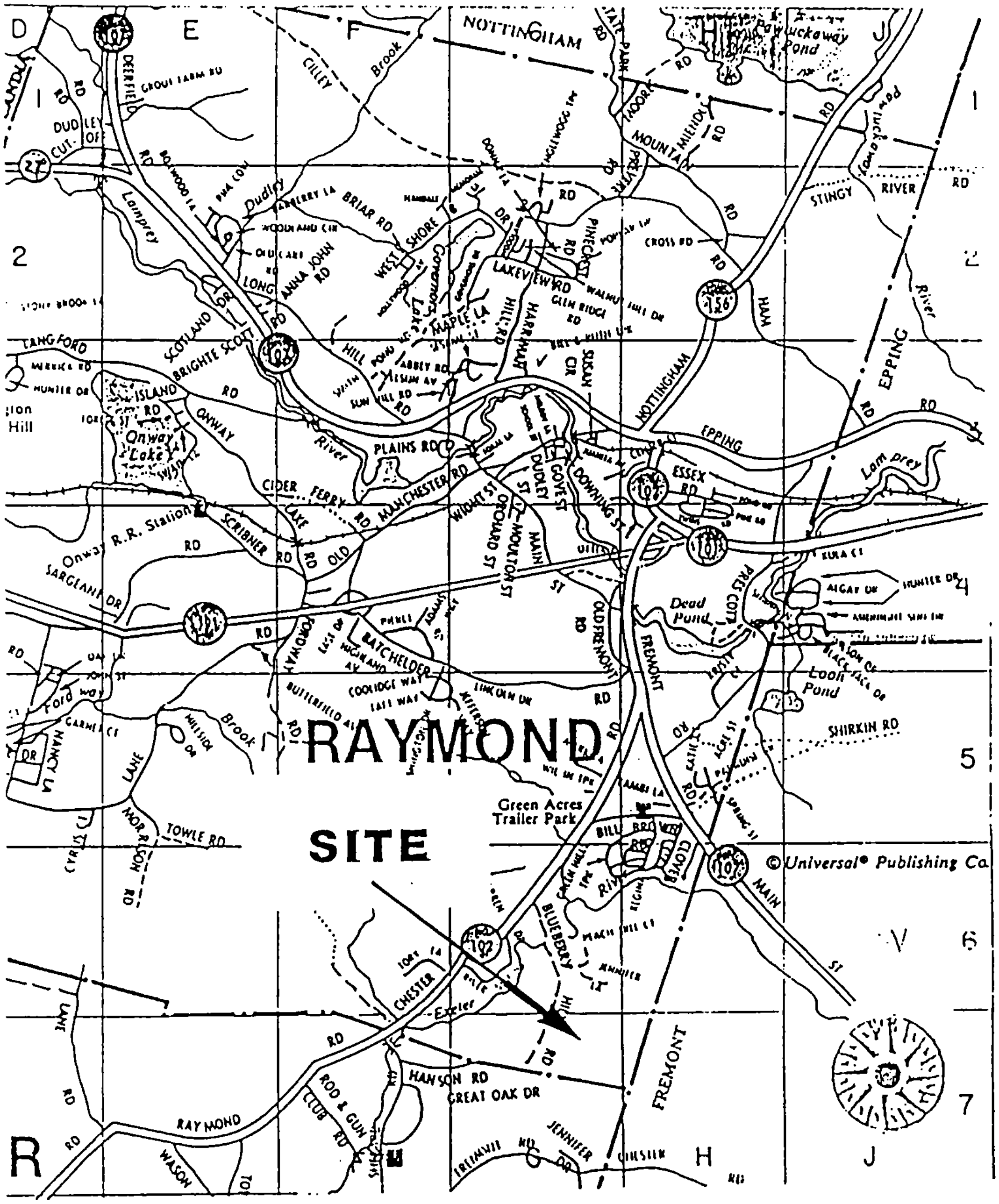

Figure 1. General location of the Mottolo Superfund Site.

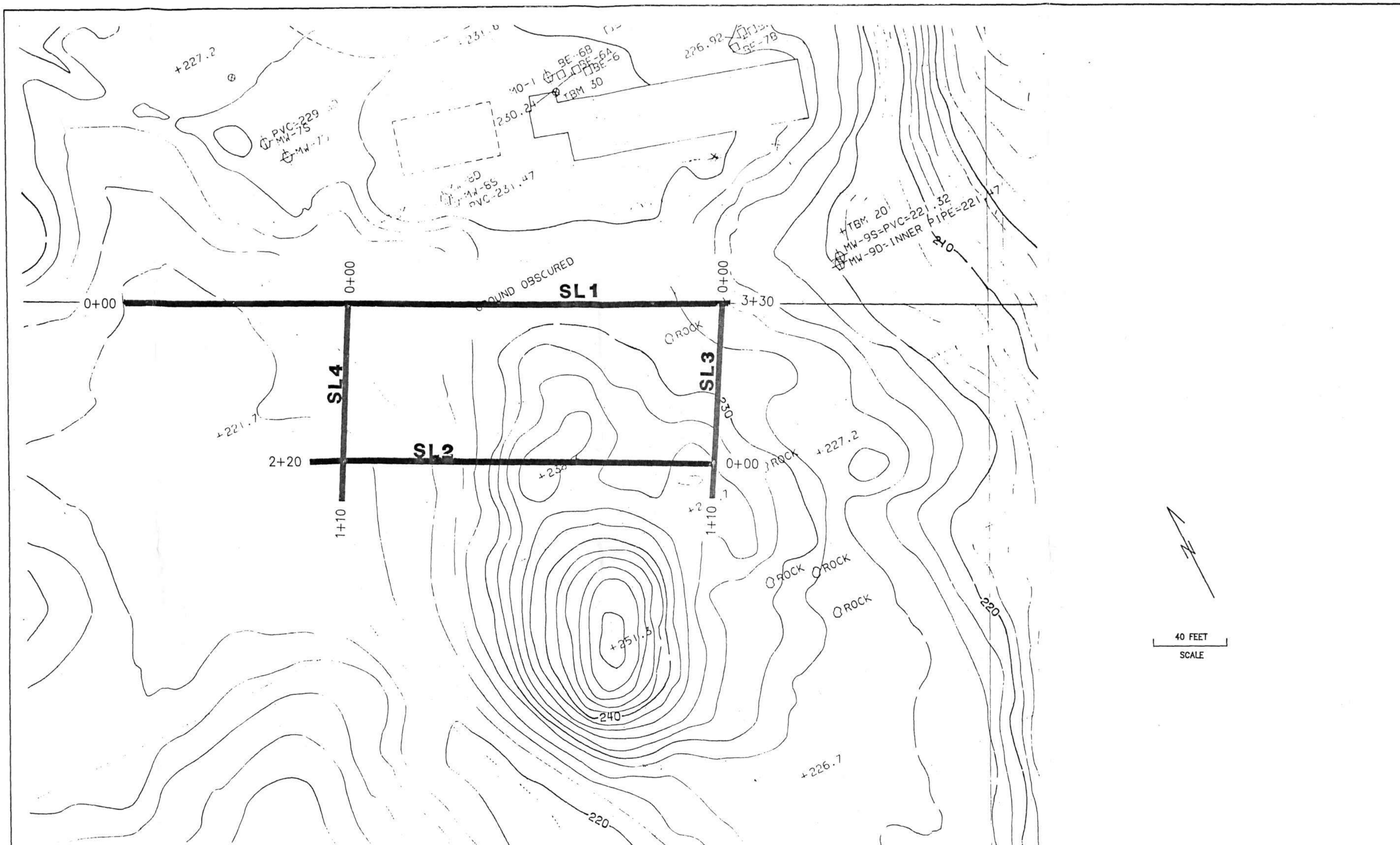

PLATE 1
SEISMIC LINE LOCATIONS
MOTTOLO SUPERFUND SITE

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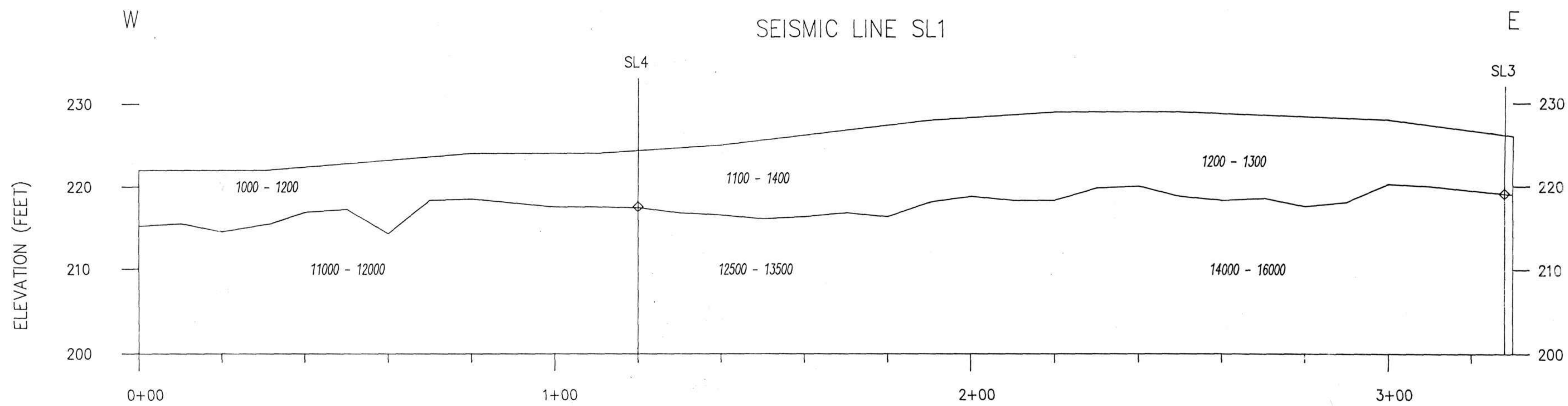
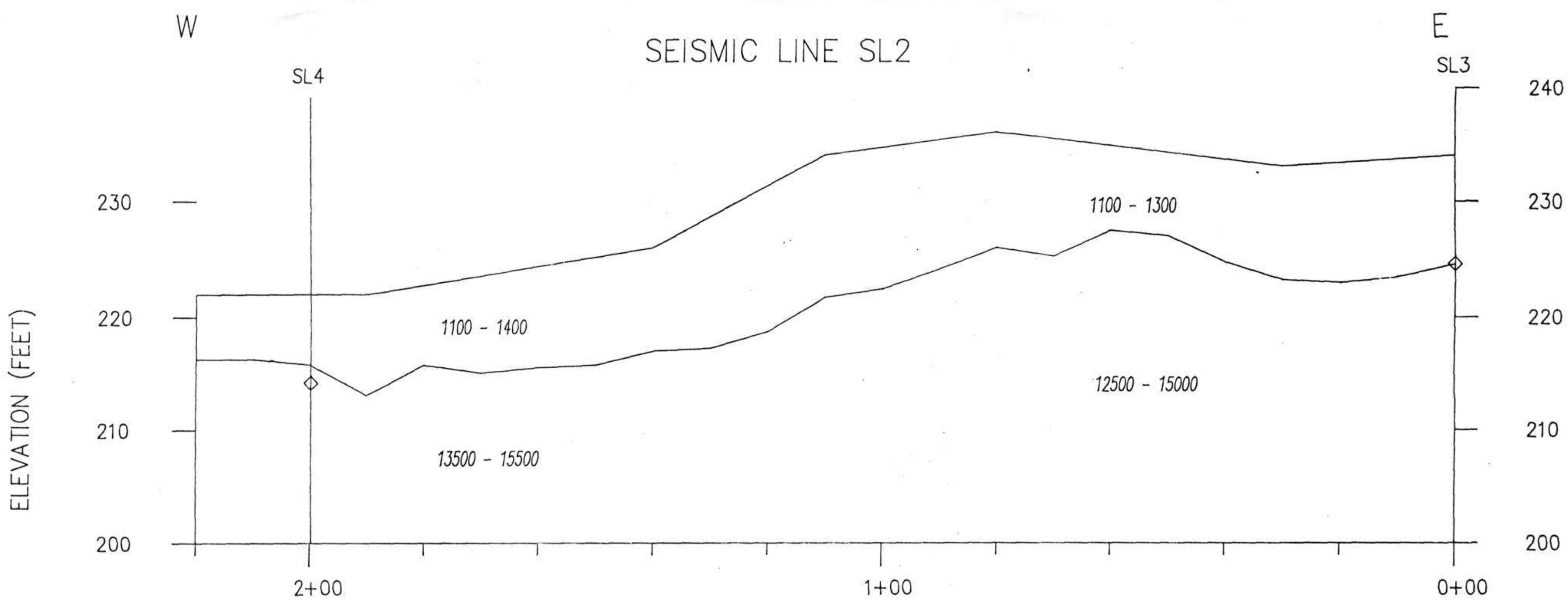
Salem, NH 03079

279 #43 — 95





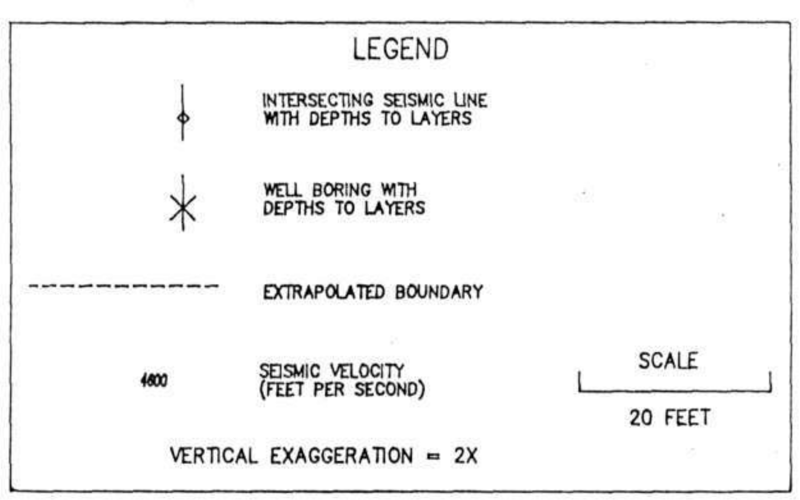


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PLATE 2
SEISMIC REFRACTION PROFILES
TWO LAYER MODEL
LINES SL1 AND SL2

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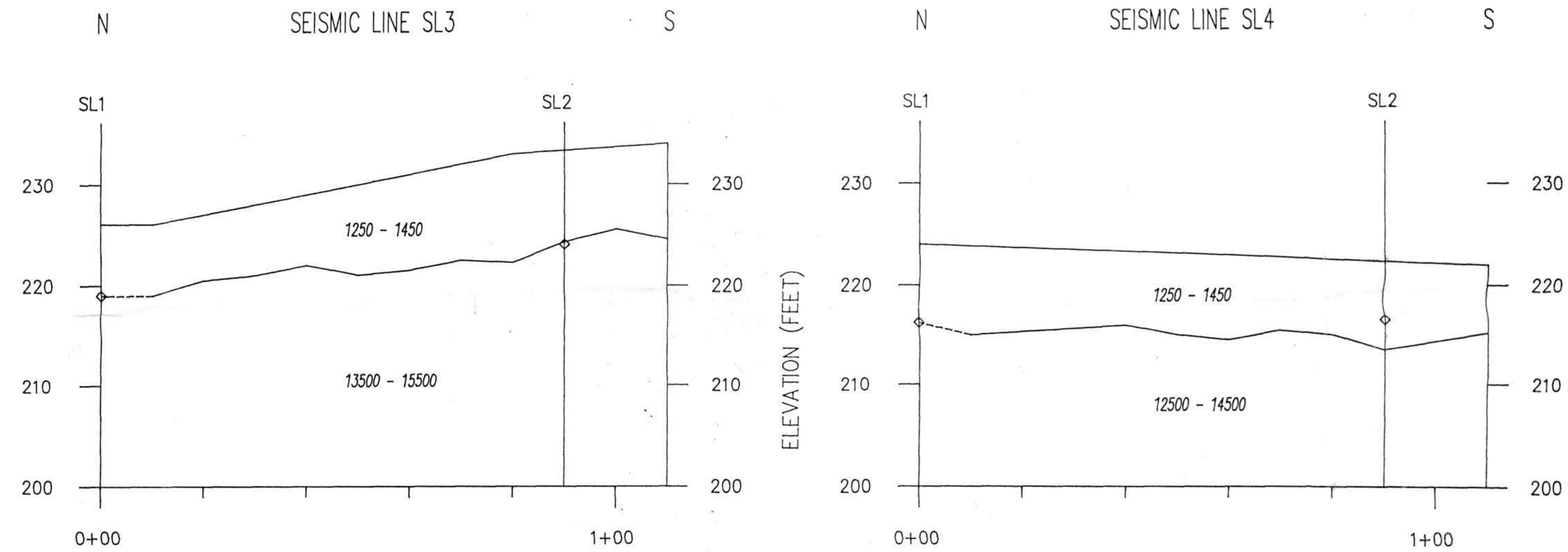

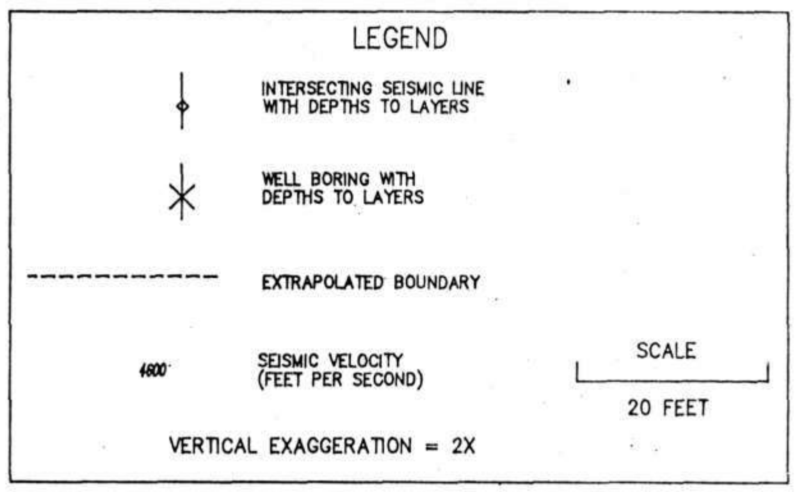

PLATE 3
SEISMIC REFRACTION PROFILES
TWO LAYER MODEL
LINES SL3 AND SL4

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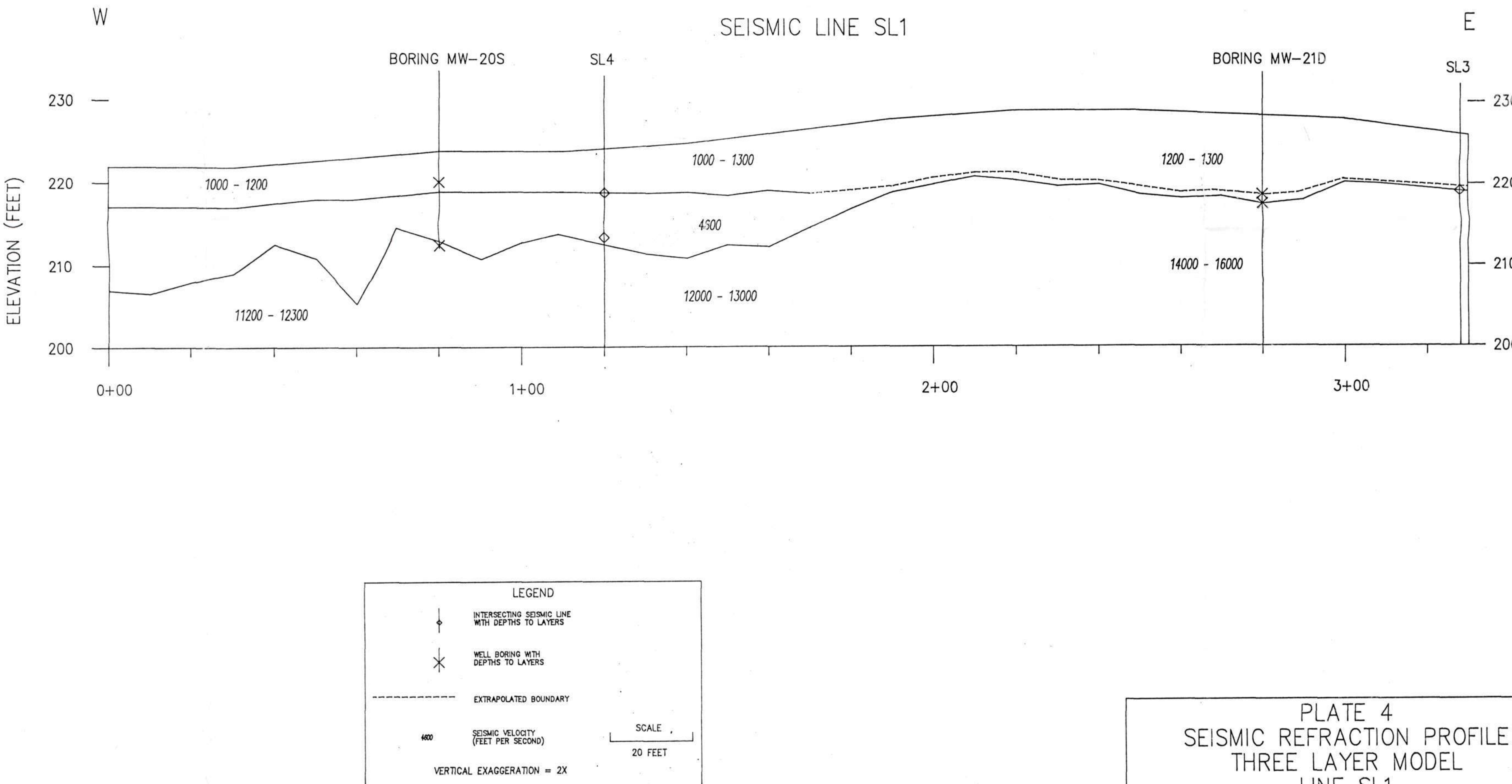

PLATE 4
SEISMIC REFRACTION PROFILE
THREE LAYER MODEL
LINE SL1

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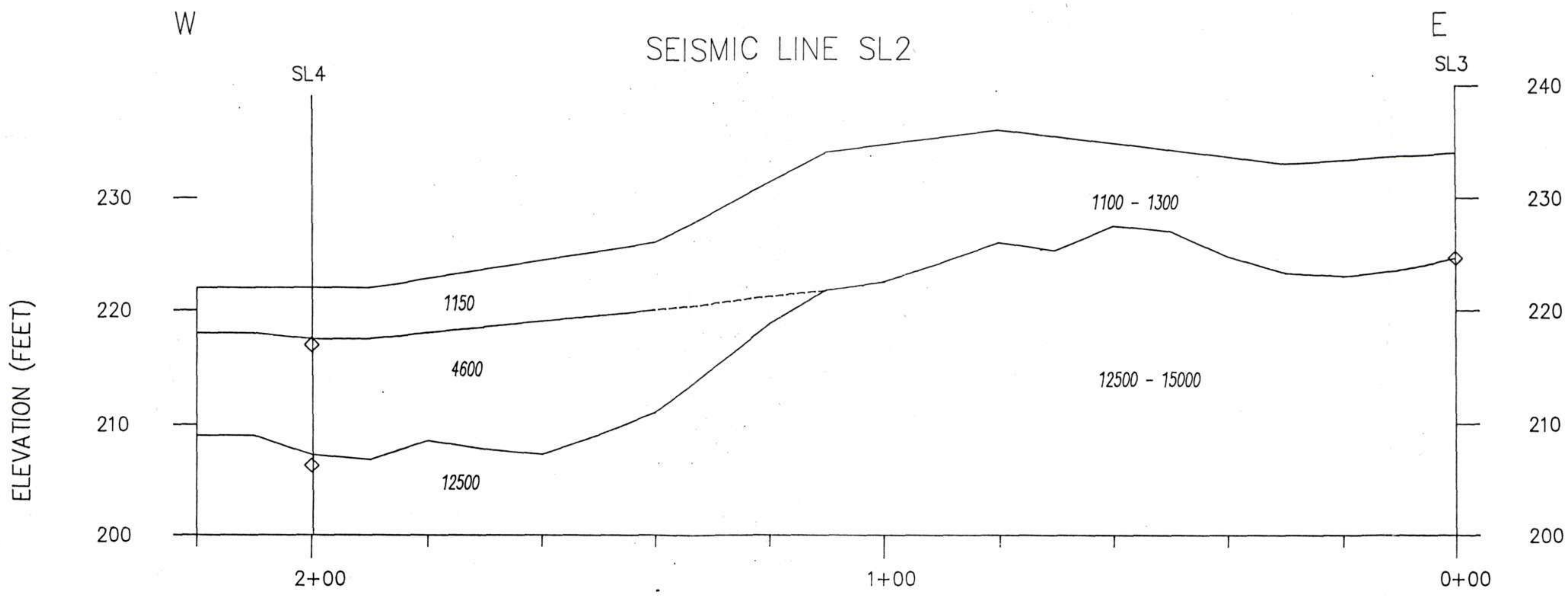

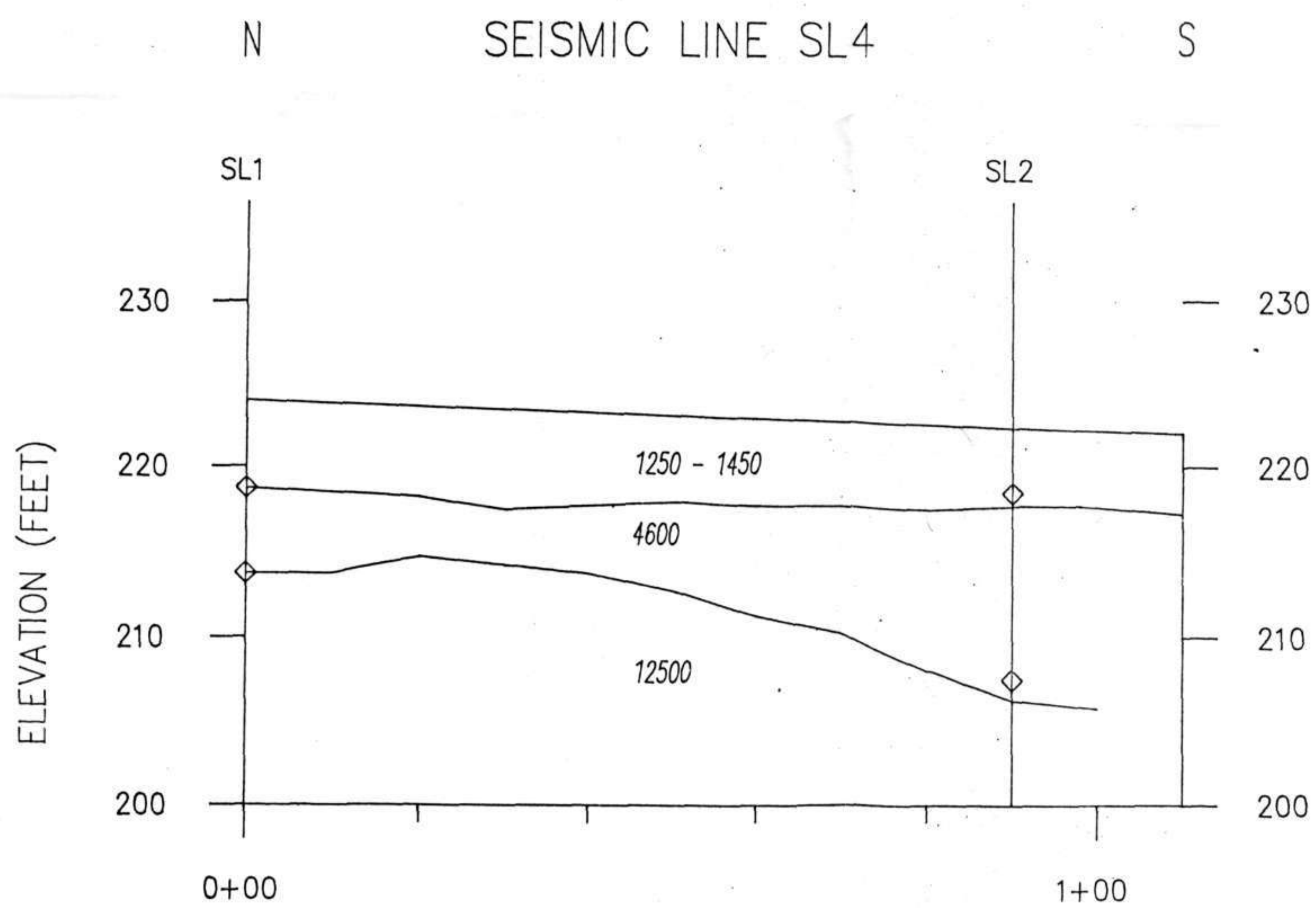

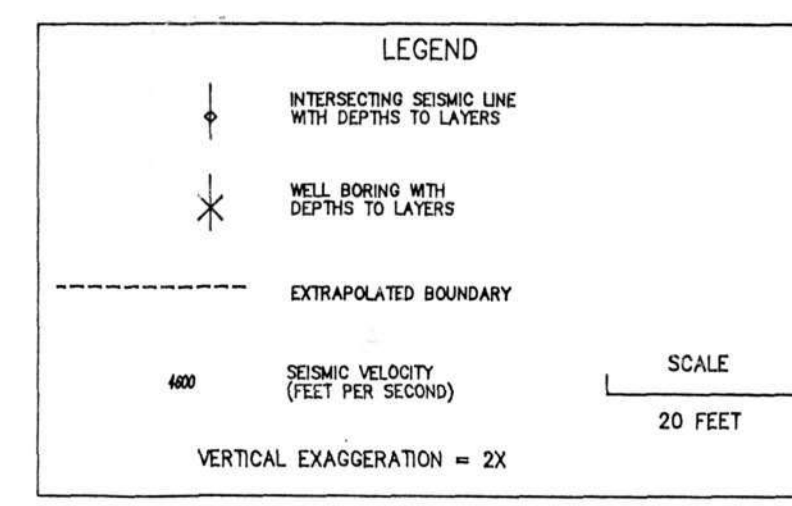

PLATE 5
SEISMIC REFRACTION PROFILES
THREE LAYER MODEL
LINES SL2 & SL4

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APPENDIX
REFRACTION FIRST BREAK ARRIVAL TIMES

DISTANCE — EACH COLUMN LISTS ARRIVAL TIMES IN MILLISECONDS TO GEOPHONES FROM THE SHOT WHICH LOCATION IS SHOWN IN THAT COLUMN

LINE SL1

-60						SHOT
0	21.10	27.10	20.70	14.30	SHOT	17.05
10	20.30	26.60	19.20	13.15	9.60	17.30
20	20.25	27.85	19.35	9.90	13.10	18.20
30	18.70	24.55	17.65	SHOT	14.05	19.00
40	16.50	23.20	15.80	9.05	15.00	19.25
50	16.35	22.65	15.60	12.95	16.05	20.25
60	17.40	24.35	16.30	16.40	20.30	22.40
70	13.85	20.15	11.20	14.55	18.05	21.15
80	13.05	20.20	SHOT	17.50	18.85	22.50
90	11.85	19.75	9.65	17.25	19.90	23.25
100	8.50	19.05	12.90	18.50	19.00	24.10
110	SHOT	17.50	14.45	18.50	19.90	24.85
170		SHOT				

LINE SL1(cont.)

50	SHOT					
110	15.90	SHOT	16.35	18.85	21.75	25.40
120	17.90	8.60	16.35	18.85	21.75	26.00
130	17.50	12.80	9.20	17.30	20.95	25.15
140	19.75	14.85	SHOT	18.10	20.95	24.45
150	21.50	16.15	9.30	17.15	20.80	23.90
160	21.55	17.20	17.15	16.00	19.75	23.50
170	23.20	18.40	18.85	14.10	19.50	23.25
180	24.85	19.55	20.50	9.05	19.05	22.95
190	22.85	18.85	20.45	SHOT	16.60	21.05
200	22.85	18.30	19.90	8.45	14.00	20.50
210	24.35	20.10	20.80	14.10	8.25	20.35
220	25.30	21.15	22.50	14.70	SHOT	19.30
280						SHOT

LINE SL1(cont.)

160	SHOT					
220	19.50	SHOT	16.80	18.80	22.60	25.20
230	21.40	10.15	14.00	18.10	20.90	25.15
240	20.15	13.60	8.50	16.35	19.20	22.80
250	21.15	15.35	SHOT	17.50	20.50	23.85
260	22.60	16.50	8.85	17.20	20.15	24.25
270	22.05	16.60	17.05	16.80	18.45	21.85
280	24.50	18.80	17.50	15.05	19.85	23.30

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DISTANCE	ARRIVAL TIMES (ms)					
290	23.30	19.50	18.35	8.60	17.55	22.80
300	23.90	20.10	18.95	SHOT	17.65	19.85
310	22.15	18.10	16.50	8.80	12.85	16.95
320	24.25	19.20	17.30	14.00	10.85	17.75
330	25.30	20.10	18.80	16.00	SHOT	16.00
390						SHOT
LINE SL2						
-60	SHOT					
0	21.30	SHOT	17.65	21.50	22.85	27.00
10	21.75	8.70	12.50	20.60	22.00	26.20
20	24.35	12.95	7.55	21.05	21.50	25.50
30	24.35	16.45	SHOT	18.20	20.80	23.60
40	23.50	14.80	8.50	17.90	19.00	22.80
50	22.25	15.55	13.05	15.60	17.45	21.30
60	21.90	16.25	13.75	11.80	17.25	21.05
70	23.75	16.85	15.80	7.30	15.85	20.85
80	24.60	20.25	18.20	SHOT	15.15	21.75
90	27.30	22.40	18.35	7.30	11.30	21.95
100	27.85	25.30	20.90	13.75	8.95	23.65
110	28.45	25.50	22.50	17.55	SHOT	23.50
170						SHOT
LINE SL2(cont.)						
50	SHOT					
110	21.05	SHOT	20.45	23.55	20.15	26.45
120	21.15	8.95	11.90	18.70	18.25	20.45
130	19.50	12.45	8.85	20.85	20.35	22.50
140	22.00	18.50	SHOT	20.35	19.05	21.85
150	20.85	18.50	10.00	19.65	18.25	23.20
160	21.05	18.15	17.55	18.10	17.40	22.35
170	21.30	18.50	19.40	15.50	15.65	20.85
180	20.25	18.15	18.60	8.70	13.05	18.60
190	22.45	20.25	20.95	SHOT	13.75	19.75
200	22.25	20.00	19.90	8.25	10.60	17.75
210	22.45	20.35	20.00	14.10	8.70	16.25
220	22.45	21.30	20.85	15.15	SHOT	15.40
280						SHOT

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Seismic Refraction Survey
Mottolo Superfund Site
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DISTANCE	ARRIVAL TIMES (ms)					
LINE SL3						
-60	SHOT					
0	13.05	SHOT	9.55	25.15	21.65	26.00
10	14.35	6.95	8.95	24.70	19.05	25.75
20	15.30	10.95	7.05	18.35	20.95	23.65
30	17.40	10.45	SHOT	17.40	19.75	23.30
40	18.20	14.85	10.00	18.60	21.50	25.40
50	18.35	14.85	11.05	15.40	20.85	24.15
60	18.95	15.75	11.75	13.50	20.00	23.85
70	20.10	16.80	12.35	6.95	18.25	24.50
80	19.65	17.05	12.80	SHOT	14.15	26.15
90	21.55	18.80	14.85	8.95	13.50	23.15
100	24.00	21.65	17.15	14.15	8.25	22.70
110	24.15	21.90	17.15	15.65	SHOT	20.50
170						SHOT
LINE SL4						
-60						SHOT
0	23.05	20.60	18.35	16.85	SHOT	17.90
10	22.15	19.55	17.40	14.60	8.70	19.05
20	22.80	19.20	17.90	9.40	13.90	20.35
30	19.90	16.35	15.40	SHOT	14.95	19.30
40	20.00	16.35	14.80	9.55	14.10	21.20
50	19.40	15.50	13.75	14.60	15.65	20.95
60	19.05	15.20	12.15	17.40	16.80	21.90
70	19.30	14.95	6.95	18.60	18.25	22.70
80	17.30	11.90	SHOT	18.25	18.25	23.30
90	17.90	11.50	10.60	21.05	20.00	22.95
100	19.65	6.70	12.15	21.55	19.50	22.60
110	19.65	SHOT	13.40	20.45	20.70	25.15
170	SHOT					

NOTE: Distance is distance along the line in feet.